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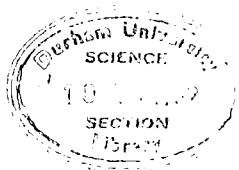
EXPLOSIVES IN THE UNITED KINGDOM DURING THE
MIDDLE PART OF THE NINETEENTH CENTURY
(With special reference to Civilian explosives)

-by-

H.S. CHILD

MS^C.Thesis

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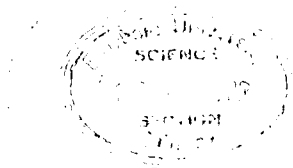
INTRODUCTION

The aim of this work will be to offer a history of the course of development of explosive agents in the United Kingdom between 1845 and 1875.

This period was chosen because a preliminary survey of the literature indicated that it was between these years that almost all of the new explosive compounds which were to offer alternatives to the traditional black gunpowder were introduced. In the event, the choice proved to be sound. Maintaining the lower boundary at about the year 1845 proved to be a little difficult because it was found to be necessary to allow a brief treatment of a few important earlier events in order to present a clear picture of what was to follow. The choice of the upper limit at 1875 began as an arbitrary choice but was found to mark a distinct end to what had been an extraordinary spate of discovery, invention, and application, in the use of explosives.

As might be expected, the rate of flow in the data is far from uniform. Within the period 1845 - 1875 there were times of great enthusiasm, activity and progress, followed by long years of discouraged quiescence. This has meant that for some years there has been such a super-abundance of material that a selection has been forced, while for other years the data is so scarce that it has been necessary to do what could be done with what came to hand and to maintain continuity as well as could be. It should, however, be said that there has throughout the whole work been a conscious effort to give a balanced treatment to each topic according to what was perceived to be its relative importance.

Named explosives will be discussed in a chronological order.



This will mean in most cases from the date of the explosive's discovery; though in the case of gunpowder it will mean from a point of significant change in its form which came about at the beginning of the nineteenth century. Each explosive will be treated under the name it was given when it was brought into use in the United Kingdom.

Some compounds stand apart as distinct lines of development and are sometimes associated only with the names of their inventors. These, however, are few and they were almost always those explosives which attracted little and often short-lived attention. Between the successful explosives and the men who invented them and promoted their use, there was interaction and competition. It will also be shown that there was often interdependence: progress in one branch of explosives technology waiting upon advance in other.

The pins marking out the chronology of invention and discovery will be the dates given for the granting of British patent protection. Patents and their specification are to the history of technology what treaties and their terms are to political history. But a patent date is established only for a British patent and cannot often be used to establish an absolute date. The practice of publishing the date, the number, and sometimes an outline specification, of recently granted patents on the back pages of technical magazines has made it possible to track the progress of invention inside the United Kingdom.

The sources studied for this work have been for much the most part, contemporary, printed, and public, works: books, cyclopaedias, technical dictionaries, magazines and newspapers; journal papers.

Very many - most - of the magazines and the articles in the cyclopaedias and dictionaries are by anonymous writers. Usually they are stolen property badly melted down - they are pieced together

from many sources without great care to disguise the fact. This has proved sometimes to be useful. These paste-up articles provide the manuscript fragments in the history of technology. The paragraphs lifted whole from long defunct and often uncollected journals, sometimes from foreign sources, provide linking information: they show particularly that the long accepted date for a discovery can often be set back by months or even years when events on the Continent can be studied.

Newspaper articles and articles from popular magazines have been much consulted but little used. The focus of such material is upon the spectacular - the first flush of excitement at the announcement of an invention, the horror of accidental explosions. The main value of this kind of material has been to place personalities at a given time and place.

Journal papers, those printed as 'Proceedings' of this or that Institute or learned society, have provided the strongest underpinning for this work. These papers are signed. They are also long, offering cumulative accounts of all that had happened over a stated period. They are informed and authoritative. There is in addition attached to these papers the record of after-discussions, 'conversazione' during which the writer of the main paper was open to having his assertions challenged and his partizan stances attacked. These particularly have been invaluable.

Had time and resources permitted, it is certain that it would have been possible to have researched and written a history which was both more extensive and more detailed. The material exists and it is accessible. Nevertheless, it is felt that within the bounds of this thesis will be found an accurate main outline of events and much interesting and illuminating detail.

Method of organising the Material

The titles of the headings under which the material for this thesis will be treated will vary in their wording to suit the topic under discussion. But where the nature of the material allows it the broad sequence will be the same. That sequence is given here in an open order, as a set of sub-aims for the work.

For each named explosive taken as the subject of a chapter in the work which follows it will be attempted to:-

1. Locate the invention or discovery as accurately as can be to a precise date and place; where this cannot be done, to offer a best approximation based upon the information held;
2. Give brief biographical information about the inventor or discoverer, where this is not already common knowledge;
3. Point out any attendant circumstances which could be held to have rendered the conditions for discovery especially favourable;
4. Offer any information which could be used to dispute the accepted primacy for the invention or discovery;
5. Outline where necessary the events which preceded the introduction of the explosive into the United Kingdom;
6. Give the British patent number and the date for the granting of the patent, and for any subsequent patents for the same invention;
7. Describe initial attempts to promote the invention in the United Kingdom;
8. Describe in detail early methods of manufacture and manufacturing machinery, testing and use, packaging, storage, handling, and transport; and the dangers and difficulties associated with all of these;

9. Suggest reasons for the disuse or replacement of a type of explosive;
10. State ways in which a given explosive might be considered to be unique in its time or to represent a first example of a compound having certain qualities, or being based upon certain hitherto unused raw materials;
11. Contrive to present an account which gives the greatest clarity consistent with the known facts, and to illustrate and support that account with apt quotation from contemporary sources.

THESIS ABSTRACT

H.S. CHILD

M.Sc. Thesis, Durham

1. GUNPOWDER

This chapter will treat of the traditional black gunpowder, the simple mixture which was the only explosive in use before 1846. Only the history of early modern gunpowder will be considered: 1820 -1875. Within this topic will also be considered those black gunpowders which differed from the standard associated with powder made according to a set formulation and method of manufacture at the Government mill.

2. MERCURY FULMINATE

It will be shown that the discovery of this compound, and the devising of ways in which it could be used to initiate the full potential of other explosives, are key factors in the development of modern explosives technology. Without mercury fulminate or a substitute for it there could not have been nearly so wide a repertoire of techniques in the use of explosives as there are today.

3. BICKFORD FUSE

While, strictly speaking, Bickford fuse is not an explosive, it does represent, like mercury fulminate, an essential enabling device in the application of all of the explosives discussed. For this reason it will be treated as an independent topic in the work, and one having a bearing on what is said of the use of explosives throughout the thesis.

4. CHLORATE EXPLOSIVES

The explosives based upon potassium chlorate were perennially attractive to the amateur and the crank; they were from the beginning shunned by both Governments and serious manufacturers. More space has been devoted to chlorate compounds in the popular magazines than the true importance of such compounds merits.

5. GUN-COTTON

Gun-cotton was the first high explosive which could be made in large quantities. It was an explosive which attracted much support in the United Kingdom. The story of gun-cotton is principally the story of a search for a solution to what was in reality a simple mechanical problem; for a means of ensuring the stability of the explosive by removing every trace of the nitrating acids.

6. NITROGLYCERINE

The use of nitroglycerine was overshadowed by the close parallel of its development with that of gun-cotton. The two explosives had similar properties and were thus in competition. Like gun-cotton, the use of nitroglycerine was under a virtual ban in many European countries for many years, following a number of serious and apparently spontaneous explosions. Only the extraordinary power of this explosive induced a few workers to persevere with its use, and to search for some means of rendering it safe.

7. WYNANTS' POWDER = SAXIFRAGINE

This composition represents a minor line of development in which a failure to find a non-hygroscopic and less corrosive ordnance gunpowder was by the use of barium nitrate turned to good account by the discovery that a modified form could be used as a civilian mining

explosive which was useful because of the gradualness with which it generated gases during its conflagration.

8. SCHULTZE POWDER

Schultze wood-gunpowder was a development parallel with that of gun-cotton. Closely akin to gun-cotton in its basic composition, it differed from it only in the extremely involved processes used to reduce wood pulp to cellulose. Schultze powder could be considered as an example of the kind of ingenuity which was later applied to 'ersatz' products.

9. NEUMEYER'S GUNPOWDER

Herr Neumeyer altered the form of modern gunpowder without greatly changing its composition. The result was a curious technological regression which was short-lived but which did arouse extraordinary interest at the time.

10. GALE'S GUNPOWDER

Mr. Gale offered a novel treatment of ordinary gunpowder which was to render it entirely safe from accidental ignition.

11. DYNAMITE

Nobel's 'Dynamite No.1' was the first all-round, powerful, civilian, high explosive. It was stable, it was quite cheap, it was plastic. It was also patented and keenly defended as such in the courts. The simple events surround its invention as an important event in the history of technology are obscured by the flurry of events surrounding its promotion. Dynamite has been more the subject of studies in pure economic history than in the history of technology. The general use of dynamite marks the end of an active period in the development of explosives and the beginning of some thirteen years during which consolidation of existing techniques was the main activity.

12. PICRIC ACID AND THE PICRATES

Neither picric acid nor the class of picric explosives derived from it were amenable to civilian application. All were essentially military explosives, suited particularly, and in practice almost exclusively, to use in the bursting charges of shells and torpedoes.

Nevertheless, the picric acid explosives represent an important advance in the history of explosives because they can be marked as the first explosives which utilised a coal based raw material, not one dependent upon agricultural resources.

13. SPRENGEL EXPLOSIVES

The Sprengel explosives are a null class, an empty cell in the classification of British explosives. There is a name and a list, and an account of certain experimental findings, but there are no representatives. The reason for the inclusion of the term 'Sprengel explosives' within the classification formulated when the terms of the Explosives Act of 1875 was drawn up will be seen to have come of causes political rather than technological. A more apt name would have been 'so-called Sprengel explosives', or, 'explosives of the 'Sprengel type'. Herman Sprengel's experiments were important from a theoretical standpoint rather than a practical one.

14. AMMONIUM NITRATE EXPLOSIVES

Explosives based upon ammonium nitrate were known in the U.K. only from a few foreign sources during the period 1869-1875. The potential of ammonium nitrate had been known since at least 1811, but its extreme affinity for water made it difficult to use in explosive compounds. It was later to become an important oxidising agent.

15. MINOR AND LITTLE-KNOWN EXPLOSIVES (Appendix I)

The chapter headed 'Minor and little-known Explosives' can represent little more than an appendix of miscellaneous data. Some of the explosives recorded could well have been the subjects of whole chapters in the main work and were not so treated only for want of space; others deserve no more mention now than they received when

they were patented. The collection will at least show what was happening at the edges of the mainstream of activity.

16. CONCLUSION

CHAPTER 1

GUNPOWDER

Gunpowder is the oldest explosive. Until the sixties of the last century it was the only explosive in regular use. Other explosives, notably gun-cotton and nitroglycerine, had been discovered, manufactured, and extensively tried at the end of the eighteenth century, but because it had not been possible to ensure their stability their use had been largely abandoned.

Gunpowder remained in extensive use throughout and well beyond the introduction and the development of all the other explosives which were discovered after 1845. The use of gunpowder diminished only where the substitute was markedly superior for a particular task; in underwater work and in hard-rock blasting. Where a cheap explosive was needed for general blasting and there were no other special conditions, such as the presence of inflammable gases, gunpowder retained its position. Where gunpowder was replaced, its replacement, in the developed countries, owed more to legislation than to any wish for a change on the part of the users.

The traditional black gunpowder was a finished invention. There was little room for improvement without a radical change in its nature. The gunpowder of 1900 differed very little indeed from that of 1800, in its constitution, the mode of its manufacture, its appearance, or its performance.

At the beginning of the nineteenth century, gunpowder had already a long history. It is the explosive of folklore. Every country in Europe has in its literature a national claimant for the invention. In everyday life gunpowder found a multitude of minor uses. With the addition of more sulphur it was used as a fumigant; it was a pigment

used for tattooing; a little gunpowder was flashed off on a wound to staunch bleeding; the nitre in it was used to cool fevers, and as a medicine for horses.

Above all gunpowder was available. Like all weapon technology the use of gunpowder had spread with great rapidity. It was available because its presence in a country was a strategic imperative. The need to have as good quality of gunpowder as neighbouring states ensured constant research and experiment. The same imperatives required that all aspects of gunpowder supply - materials, manufacture, export, import, storage, distribution - were a matter of State policy in all European countries. The need to control gunpowder supplies led early to the setting up of secular administrative machinery.

The need for the quantity production of gunpowder called into being adaptations of existing machinery for its manufacture. Knowledge of the attendant technology, of powered machinery, went with the dissemination of the knowledge of gunpowder.

On the nature of Gunpowder

Gunpowder is a mixture. Its constituent particles of saltpetre, charcoal and sulphur, even were they ground together with the utmost care, would, nevertheless, appear under a microscope as a collection of white, black and yellow fragments.

The immediate cause of the rapid burning which takes place between these fragments is more of a mechanical phenomenon than a chemical one. And it is because the events do not occur at the directly molecular level that an empirical, a naive, almost, view of what takes place when black gunpowder is ignited can be offered.

A single grain of gunpowder could be described as a close packed population of three quite different kinds of particle or

fragment. Individually, the three constituents will burn or will sustain burning. But each has a different immediate reaction to heat:

saltpetre fuses and gives off a little of its oxygen; charcoal may begin to glow; sulphur will melt, and it will give off sulphur dioxide. These things would happen whether the particles were a few microns across or each the size of a golf-ball; though only in the former case might we reasonably expect to see the beginning of an explosive conflagration.

The burning of gunpowder begins not with a reaction but with an interaction. When a localised source of intense heat (a red hot poker was known to be a more sure means of touching off powder than a lambent flame) comes into contact with gunpowder it acts, in the first instance, upon all three of the constituents; and all three react according to their individual chemical properties. It is the change induced in each of the constituents in the presence of the products of each other's reaction to the heat which allows the initiation of the mutually accelerating interaction. The sulphur melts and gives off sulphur dioxide; in the presence of the dioxide the charcoal ignites at a lower temperature; because the charcoal has ignited the greater heat it generates induces the saltpetre to begin to give off its oxygen, and so on.

The reaction may be between the products of the heating, but the interaction takes place on the physical surface of the individual particles. Under certain conditions the process might even be observable.

The discovery of Gunpowder

It is because gunpowder is a mixture and not a compound that it was discovered so very long before any other explosive.

When taken by weight, the sulphur and the charcoal in black

gunpowder represent a very much smaller proportion of the mixture than does the saltpetre. This is not important in gunpowder because proportion by weight is not crucial in a mechanical mixture in the way that it is in a chemical compound. It is in molecular combination where the proportions by weight are absolute. To foreshadow a little, the discovery of mercury fulminate depended upon certain compounds being brought together in quite precise proportions. The band within which that compound would have been precipitated in a state pure enough for its useful properties to have been displayed was narrow. In gunpowder this was not so.

In gunpowder mixtures it is merely a convenient convention to express the quantities in the recipe - for it is nothing more - in proportions by weight. But it is the volume of the constituents, the sheer numbers of the particles present, each retaining its own chemical identity until the instant of burning, which is of importance. Charcoal, particularly, is, weight for weight, much more bulky than an equal quantity of either saltpetre or sulphur, and consequently contributes more particles to the mixture - which is why black gunpowder is black.

The proportions of the constituents in a gunpowder may vary within extraordinarily wide limits without there being an absolute loss of the ability to yield an explosion.

The early history of gunpowder shows that the proportions of the three constituents used were greatly different from those which were finally chosen for 'modern' gunpowder. To take just one example from many, and this is by no means the extreme case, the proportions given by Niccolo Tartaglia in 1546, which were quoted by Abraham Rees in his Cyclopedia* of 1820, gives the proportions 4 : 1 : 1. If these

* Rees's Manufacturing Industry (1819-20). 'A selection from the Cylopaedia or Universal Dictionary of Arts, Science and Literature.' Ed. A.R. Cossins, Vol.III, p.136 et seq. Published: David & Charles Reprints, 1970.

proportions are converted into percentages, and then compared with the percentage proportions given for British gunpowder of the nineteenth century, it can be seen that:

Saltpetre

$$75\% - 66.66\% = 8.33\%; \quad 8.33 / 75 \times 100 = 11.11\% \text{ Difference}$$

Charcoal

$$15\% - 16.66\% = -1.66\%; \quad -1.66 / 15 \times 100 = -11.11\% \text{ Difference}$$

Sulphur

$$10\% - 16.66\% = -6.66\%; \quad -6.66 / 15 \times 100 = -44.44\% \text{ Difference}$$

This width of range within which a composition can vary and still be induced to work as an explosive has an implication for the probability of gunpowder being discovered.

Because even a small admixture of sulphur and saltpetre with charcoal, even of impure saltpetre and sulphur, is likely to have a visible effect when these are burned, even if the effect is only a slight tendency to throw off sparks, the phenomenon is attractive. And a small variation in the proportions of either the saltpetre or the sulphur will alter the effect. Since saltpetre, after the universally common charcoal, was the more plentiful of the ingredients; the variation was, therefore, likely to have been in a profitable direction.

The coming together of the three necessary constituents was not a very great improbability. Charcoal and saltpetre would have come together wherever a fire was lit on ground which had effloresced a bloom of nitre crystals under hot sunshine. Sulphur when burned has just those properties, an eerie blue flame and a throat catching smell, which would have ensured that it passed from its few sources into the stream of trade.

The combination itself may be unique. It is difficult to suggest two substances other than sulphur and the nitrates of sodium or potassium which are stable enough to occur native in nature, and which will when mixed with charcoal give rise to a similar effect.

The discovery of gunpowder can be thought of as a case where some unknown dabbler 'scooped the pool' along an entire line of invention to carry away the only prize which was to be offered for centuries afterwards. It was precisely because gunpowder was the only fortuitous combination of the compounds - virtually the only compounds which would have served - which did not require an altogether more advanced chemical technology for their production, that it remained for so very long as the only explosive.

The Proportions of the Constituents used in Gunpowder

British gunpowder, from at least 1781* onward, was commonly made in the proportions of 75 per cent of saltpetre, 15 per cent of charcoal, and 10 per cent of sulphur. This proportion was by weight, and it was the proportion used to compound gunpowder made for military purposes particularly. Thus, the formulation has stood now for quite two centuries without there having been any need to change it. However, what has suited the British has not found equal favour with other nations. The French were attached as fondly to their own recipe of 'six, as, as,' : 'Six, one, one'. But the small variations in the proportions used were not considered to be of the greatest importance. Abraham Rees (cited above) displays a commonsense attitude to the problem:

*THE MANUFACTURE OF EXPLOSIVES, Vol.I, page 176, et seq, OSCAR GUTTMAN, Pub. Whittaker, London, 1895.

"What this proportion is has been ascertained by experience; and it seems to be generally agreed, that in any quantity of powder, three-fourths of it should be saltpetre, the remaining one-fourth consisting of equal quantities of sulphur and charcoal. This is the proportion followed by the French, and by most nations in Europe: we indeed pretend to a greater nicety in our proportions; though it is said, they do not greatly differ from what is here mentioned; nor is it certain that they are preferable: this, however, may be depended upon, that no method of proving powder, hitherto generally practised in England, could at all ascertain the difference; and other powders made with the proportion are nothing inferior to ours."

Gunpowder which was specifically made to be used for the purposes of blasting might be made with a somewhat different formulation. However, the knowledge that this was so may not have been so widespread as might be supposed. The proportions 75 : 15 : 10 were so commonly published that it is understandable that even the well-read layman may not have known that the composition of mining powder was a little different. The fact is very seldom alluded to in the journals. An unequivocal statement of the distinctions is given in Cundill's Dictionary* of 1893:

"Blasting powder and gunpowder are sometimes spoken of by retail dealers as if quite different substances. They are, of course, identical, or rather blasting powder is simply a cheaper and inferior class of gunpowder. At the same time Desortiaux** (p.600), points out that not only is a powder rich in charcoal cheaper than ordinary powder, but that it may be expected to furnish a larger volume of gas when exploded, and he quotes Piobert in support of his theory. Hence for blasting purposes, it is quite possible that a cheap powder, poor, comparatively speaking in saltpetre, may be equal, or superior, to one of the ordinary composition."

The addition of sulphur at the expense of the proportion of saltpetre was the practice in the making of some mining powders at

* A Dictionary of Explosives by Major J.P. Cundill R.A., H.M.'s Inspector of Explosives, London, 1893, p.19.

* * Desortiaux' translation of Traite sur la poudre, les corps explosives, et la pyrotechnie by Drs. J. Upmann and E. von Meyer.

least. In the course of a discussion on the analysis of gunpowder which appeared in The Engineer for 14th December 1866, the composition of mining powder is given as '65 per cent saltpetre, 20 per cent sulphur, 15 per cent charcoal'.

Black gunpowder was not an ideal mining explosive. Used underground it gave off much smoke which was not easy to dissipate with the primitive ventilation of the time; it was too shattering in its effects upon the coal or stone being blasted; it was too hot in its action and tended to ignite explosive gases and dusts in the mine. The attempts to modify and to replace black gunpowder used in mines will be discussed later in this work.

Sulphur

Sulphur is the one constituent of gunpowder for which the location of supply was more or less fixed. Sulphur for gunpowder - any European nation's gunpowder - was Sicilian sulphur. Throughout the nineteenth century this source of supply was firmly in the hands of British merchants. What had been denied to the French by the presence of Nelson's frigates at the beginning of the century was to be largely controlled by British capital until almost the end of the century. Louisiana sulphur was discovered in 1865, but no way was found for extracting it until the introduction of the Frasch process in 1891.

Some idea of the output of the Sicilian refining kilns can be gained from the information that in the year 1868 the quantity of semi-refined sulphur exported was 4,052,000 hundredweights (205852 tonnes).^{*} This quantity was available for all imaginable uses of sulphur. The actual demand for sulphur which was to be used specifically for making gunpowder must have been quite small. A hundred tonnes of refined

^{*} Wagner p.195 et seq.

Handbook of Chemical Technology by Rudolf Wagner, Phil. Pub. Churchill, London, 1872, p194.

sulphur will make a thousand tonnes of gunpowder. One small merchant steamer could carry in its holds sufficient sulphur to make the gunpowder for a major campaign. A stockpile of a few thousand tonnes would have seen a nation through a long war.

Sulphur arrived at the mills in a state of refinement which allowed it to be used in powder without further processing. However, at Waltham Abbey where best quality gunpowder was made under government contract, sulphur was passed through a secondary refining process. Both Wagner* and Guttman** give illustrations of the same apparatus; Guttman describes the plant illustrated in his book as being that employed at Waltham Abbey.

The apparatus was simple. A cast-iron pot over a furnace was filled with the partially refined sulphur. Leading from the pot there was a flue with two branches. By means of a flap valve, the vapours coming from the heated pot could be diverted either to a large beehive dome or to a smaller cast-iron condensing pot. At lower temperatures the vapour was allowed to go into the beehive where the 'flowers of sulphur' was sublimed and condensed; at the higher temperatures sulphur was distilled over and diverted to the cast-iron receiver, where it could be tapped off into moulds made of wood.

The flowers of sulphur from the above process were simply used as 'grough' for the next charge.

Flowers of sulphur is always said to have been considered unsuitable for gunpowder making because of the presence of sulphuric and sulphurous acids formed by oxidation when the tiny crystals were sublimed in the air of the beehive dome. The presence of these acids did not affect the action of the gunpowder, it is rather that gunpowder

* Handbook of Chemical Technology by Rudolf Wagner, Ph.D. (p.194), Tr.W. Crookes, Pub.Churchill, London, 1872.

** The Manufacturers of Explosives by Oscar Guttman (p.53), London, 1895.

made with flowers of sulphur gave off acid vapours as a product of its explosion. Sulphur for government gunpowder was tested with litmus for acidity: it was required to give a neutral indication.

Charcoal

The destructive distillation of organic materials of many kinds was the subject of much attention during the whole of the nineteenth century. Retorts practically identical with those used for burning gunpowder charcoal were used to distil products from bones, tree stumps, peat, shale, and other cheap and abundant raw materials. Increased in size, and given suitable condensers and scrubbers, the cast-iron retort was to be employed in the making of town-gas from coal.

The difference between the preparation of all of the above mentioned products and the preparation of charcoal for gunpowder making lay in the exceptional care taken to produce a good clean, and above all, uniform, finished article.

In order to achieve a satisfactory charcoal it had been necessary to find an alternative to the traditional pit-firing method of carbonising wood. Gunpowder made from such charcoal was called 'pit-gunpowder' and held to be fit only for making fireworks.* From the end of the eighteenth century onwards, charcoal for gunpowder was burned in iron retorts. The inventor of the retort method of preparation was the Reverend Richard Watson. Watson, who was Professor of Chemistry at Cambridge, and who later became Bishop of Llandaff, devised the iron retort method, the 'cylinder' method as it came to be called, at the Government's behest with the express intention of improving the strength**

* Engineering, 4th January 1878, p.1 et seq.

** Transactions of the Newcomen Society. Vol. XVIII, 1937-38, pp.61-68.

of military gunpowder by the use of better charcoal. The first kilns were built at Hythe in Kent during 1778.*

(It is remarked that the date of the introduction of 'cylinder' gunpowder by the British follows closely upon the appointment of A.L. Lavoisier as superintendant of the French state powder mills and his achievement of a very marked improvement in the power of French gunpowder by the introduction of new methods for purifying saltpetre). **

Most accounts of gunpowder manufacture include more or less detailed descriptions of charcoal making. The changes which can be noted in the plant itself are a gradual movement from earlier arrangements where the retorts had to be heated by an outside fuel supply, to designs which allowed the gases driven off during carbonisation to be utilised so fully that the kiln was practically self-sustaining once it had been started.

Kilns were operated continuously during the entire six days of the working week. It is not, therefore, surprising that the life of the plant, cast-iron cylinders and brickwork, was seldom above three years. This allowed innovations to be introduced quickly.

A very detailed description of typical kilns is given in a paper, "No. 1,519 - 'On an Economical Method of Manufacturing Charcoal for Gunpowder', by George Haycraft, F.C.S., Assoc. Inst. C.E., which was printed in the Proceedings of the Institution of Civil Engineering, Vol. L. of 29th May 1877. The paper is concerned with the introduction of new charcoal retorts, but the discussion at the beginning and at the end of the paper considers plant which had formerly been in use. It will be useful to quote some parts of this paper:

* Oscar Guttman, in The Manufacture of Explosives, gives this date as 1797, not 1787. In this he is probably in error.

** LAVOISIER, J.A. COCHRANE, (Constable, 1931), p.46, et seq.

"The first method is practised at Her Majesty's Royal Gunpowder Factory at Waltham Abbey. The retorts, or cylinders, as they are technically called, are of cast iron, about 2 feet 6 inches (76.2 cm.) in diameter, and 3 feet 6 inches (101.6 cm.) long. They are set in brickwork in groups of three, side by side, so that the heat of the furnace, which is placed at the end, may play all around them before entering the stack. The exterior of the cylinders, or retorts, is protected from the direct action of the fire, by a casing of brickwork or tile. Each cylinder is provided at the back, on its upper side, with an outlet pipe for the escape of the gases to a lower horizontal pipe behind the cylinders, and common to them all. To this is attached another horizontal pipe, at right angles, to convey the gases into the furnace for combustion. Every cylinder has a tight fitting door in front, firmly fixed by a powerful screw. In this way the gases are certainly consumed; but the resulting heat is destructive to the furnaces and brickwork. The only merit of the arrangement is that the gases are got rid of in the least offensive manner..."

"The third method, formerly practised at the gunpowder works of Messrs. John Hall and Sons, at Faversham, differs from the other methods only in the mode of dealing with the gases, which are conveyed along a series of pipes, through tanks, in and out of which a constant supply of cold water is made to flow, in order to effect through condensation of the gases into tar ... which are allowed to run away into the sea to waste."

The making of charcoal, even as late as 1877, was still very largely an empirical process:

"With regard to Sir William Armstrong's question as to the method of determining when the charcoal was sufficiently burned, a man who was practically acquainted with the process opened a small door and looked into the sub-flue: he could there see the burning gases change colour; when they turned a deep violet the gases were nearly expelled, and in a few minutes the charcoal would be ready. It was a matter of judgement and experience, which, however, could be easily attained."

There was a wide variety in the qualities of charcoal made. The differences were between civil and military gunpowders; and within the civilian gunpowders there was a very wide range of qualities in both the charcoal used and in the finished powder.

"In private powder works such as those at Faversham, charcoal could be used which would not do for military purposes ... where several different classes of powder were made, including blasting and common powders, inferior charcoal could be employed ..."

However, at Faversham at least, there was a lower limit to the quality of charcoal used.

"In the retorts at Faversham no second quality charcoal was produced, consequently, for gunpowder of the lowest type (African) charcoal for best ordnance gunpowder was used."

In general, it can be said that the charcoal for large grain gunpowder was made from billets split from logs of black alder and white Dutch willow, while the charcoal for the best quality of sporting gunpowders and for military small-arms a charcoal was made from carefully graded saplings of the bush, dogwood. This material was not, however, always in good supply.

".... for a first-class strong powder, the black dog-wood is said to be best, but its great costliness prevents its being largely adopted."

Engineering, 4th January 1878, p.1.

Where dogwood was not available, lightly carbonised willow branches seem to have been an acceptable substitute.

(The choice of dogwood from among the many hundreds of varieties of woods growing in the British Isles is remarkable. The bush is only common in some areas. No record of any extensive trials of woods for charcoal making can be found before the nineteenth century. The use of dogwood may have come about after long years of trial and error. The extent of the improvement offered by the use of dogwood charcoal is uncertain. Where only one propellant is available, the users are apt to have a keen perception of small differences in performance).

Some idea of the importance attached to the use of the best available wood for the making of military powder can be gained from the information that when the Government of India reconstructed three of its own gunpowder mills in order that they could more efficiently supplement the Home supply, very careful consideration had to be given to the choice and to the certainty of supply of a substitute for dogwood:

"In all respects save one, the Ishapore powder is made from the same materials and in the same way as at Waltham Abbey. That exception is the charcoal. The dogwood, alder, and willow used in England are not procurable here in sufficient quantities, though an experimental plantation of the last is now being laid out by Colonel Boyle. In their place the stalk of Dhallrush, known as Urhun (Cytis Cagan) is used. This is a favourite crop all over India, but the charcoal made from it has this drawback, that it is more absorbent than that used at Waltham Abbey, and it is feared that the powder, though quite as pure, will not be so durable..."

The Manufacture of Gunpowder in India

Engineering 21st May 1869.

The idea of using the stalks or haulms of plants grown for some other purpose was by no means novel. Spanish and Italian gunpowders were commonly compounded from charcoals made from burned hemp stalks.

The necessary differences between charcoal made for propellant gunpowders and charcoal made for blasting powders were, firstly, that the quantity of residue left from the burning of the powder was crucial in propellant use, while it was relatively unimportant in blasting; secondly, that propellant powder should ignite very easily and should burn with great speed and regularity, again, this was of less importance in blasting powder; thirdly, that because blasting powder was used in such huge amounts when compared with the amount of propellant powder expended, it had to be made as cheaply as could be.

In outward appearance charcoal intended for small-arms powder was soft and light, and could sometimes have a reddish colour owing to its having been only lightly burned; charcoal which was to be used for blasting powder and 'pebble' powder for heavy ordnance was black, over-burned, and rang metallically if dropped upon a hard surface.

The use of juniper branches which were peeled before being charred is noted for the powder mills of the English Lake District. The plant was known locally as 'savin'. It cannot be said with any certainty

whether this was used greatly, or, indeed at all, during much of the nineteenth century.* It seems unlikely to have been used to make mining powder charcoal because the supply of savin must have been limited.

Saltpetre

From at least the middle of the seventeenth century, British saltpetre supplies came exclusively from India, and was in the hands of the Honourable East India Company. This placed England in an enviable position in respect of a sure supply of crude potassium nitrate.

A most comprehensive and detailed description of the collection and partial refinement of saltpetre in and around the Indian province of Bihar during last century is given in Chapter IV of Explosives (Vol. I. History and Manufacture) by Arthur Marshall, A.C.G.I., F.I.C., F.C.S., J. & A. Churchill, London, 1917. Nothing has been found in the course of this study which can supplement Mr. Marshall's work.

Essentially the same process for inducing the formation of nitrates as was utilised in India was employed in Europe. The difference lay in the yield. Nitrates formed more quickly and perhaps more plentifully under tropical conditions. The position of the rest of Europe in respect of saltpetre production is summated shortly in a book which was published towards the middle of the century:

"The process (extracting nitre from stable waste and wood ashes) was known to and described by the chemist, Glauber. In Prussia and in Sweden the making of nitre has been cultivated as a piece of state policy. The King of Prussia obliged his farmers to build their fences of nitre forming materials, which, after a few years, were taken down and appropriated. In Sweden, so careful is the Government on this point, that each farmer is obliged annually to furnish a certain quantity, which must be paid in kind - the Government will not compound for it - thinking that by following such a course it guards against the injurious consequences which might arise during a war, if the supply of nitre were drawn exclusively from abroad."

* The Gunpowder Mills of Westmorland and Furness by Paul N. Wilson, O.B.E., D.S.C., M.A., D.L., M.I.C.E., M.I. Mech. Proceedings of the Newcomen Society (1962)

Projectile Weapons of War and
Explosive Compounds by John Scoffern M.D.,
London: Cook & Whitley, 1852, p.43.

English saltpetre may have been as important a strategic material as English gold was during the French wars at the end of the eighteenth and the beginning of the nineteenth centuries. According to Wagner:*

"It may be noted that this importation is steadily increasing, there being, in 1860, 16,460,300 kilos., and 1868, 33,062,000 kilos of the salt being brought into England; and, indeed the production of saltpetre from natural sources in Europe is now limited to a very few and unimportant localities."

Saltpetre made 'by conversion' from Chile saltpetre was not used for gunpowder in England, and therefore will not concern us here. Wagner also deals with several of these processes in some detail.

The Refining of Crude Saltpetre

The method devised for the purification of crude saltpetre changed hardly at all between, at the very least, 1820 and 1914. Descriptions of both the apparatus used and the processes carried out agree closely across the whole period. The differences are only those of minor variations in the capacity of the vats and in the time allowed for each stage of the work. This may be nothing more than a reflection of the increasing scale of operations as mills became fewer, and larger.

The system was simple, being based upon the knowledge that nitre is more soluble in hot water than are the contaminating salts: in a cooling saturated solution of unrefined saltpetre with hot water, the chemical impurities will crystallise out first and sink to the bottom of the vat. Separation by differential crystallisation has long been widely used in industrial chemistry.

Early accounts of the process give the percentage of impurities as

* Wagner (p.136) et seq.

being as high as 20 per cent; later estimates have it as low as 5 per cent. This may indicate that additional refining was carried out in India before shipment in order to save on the cost of freightage.

The main impurities were sand and organic matter, and the chlorides of potassium, magnesium, and sodium. The proportions and variety of these impurities in a given consignment were no doubt determined by the place of origin.

The following is given as a description of the method used in the refining of potassium nitrate for gunpowder making. The aim has been to write a description which is concise and generalised, one which refers to no particular time, and no particular works or mill, but which will show how an apparently primitive but clearly ingenious method had been discovered by which large quantities of saltpetre could be highly purified.

The yellow-brown crystals of unrefined 'grough', mixed with about 40 per cent of impure saltpetre residues from previous boilings, were dissolved in cold water which was itself also charged with some saltpetre from its being used in earlier processes. There was thus always a considerable float of nitrate retained within the refining cycle. This should, however, be regarded as a necessary priming rather than as an outright loss.

Regardless of the size of the boiling copper being used, the proportion of water to salts with which it was wished to begin the process stood at about .66 of water to one part of unrefined saltpetre. Naturally it would have been appreciated that not to have begun the boiling as close as could be to the saturation -precipitation point of the impurities would have meant a waste of both fuel and time in the boiling off of excess water.

Even though the largest boiling copper could take 2032 kilograms of crude saltpetre, the operation was essentially a hand-process throughout. No instruments of any kind, not even a thermometer, are ever alluded to. Saltpetre refining must have depended entirely upon the experience and insight of the operative to achieve an optimum yield of properly purified saltpetre from each boiling. This is not, however, to say that the larger mills, from the beginning of the century, did not employ qualified chemists to analyse the output.

After the solution had been allowed to stand overnight, a fire was lit under the boiling copper, and within about two hours the mixture was raised to 300°F (149°C) at which temperature the crystals had dissolved and the solution had begun to boil actively.

It was at this stage that any organic material was skimmed off. Earlier sources sometimes mention that a handful of glue size was added to the copper just as the solution was about to come to the boil. The glue was to act as a fining agent, something to cause floating impurities to stick together so that they could more easily be collected and skimmed clear. Since this practice is not described in later material it can be supposed that it was no longer necessary when the crude saltpetre came to the mill with a much smaller proportion of organic impurities than before.

When the solution had been cleared of scum, the surface was showered with cold water. This was done in order to cause any chlorides held within the boiling action at the surface to sink. The fire was then drawn from under the copper, or was allowed to go out.

Within an hour the temperature had fallen to 220°F. (104.4°C). At this temperature the chlorides crystallised and were precipitated out on to the bottom of the copper. The nitrate remained in solution.

Using a siphon or a handpump, and taking care not to stir up the layer of impurities onto the bottom of the copper, the still cooling solution of saltpetre was run into a shallow tank. From the tank the liquor was then released through taps into cone-shaped filters of Dowlas cloth.* By that time the solution was close to its crystallisation temperature and the filters had to be kept clear of saltpetre by having hot water flushed through them from time to time. Again, this water was returned to a later boiling.

The liquor, as it was called, coming from the filters was now run into a second shallow copper cooling tank. In this tank the liquor, in which the crystals of saltpetre were being formed quickly, was constantly stirred with a wooden rake to prevent the formation of large crystals which could retain water in cavities.

Small crystals of saltpetre, 'flour of saltpetre', had then to be scooped from the tank and thrown onto an inclined screen which was covered with fine copper mesh.

After being allowed to drain, the purified saltpetre was again washed. The most common practice was to give two thorough showerings followed by a final immersion. These last washings gave successively lower returns of dissolved nitre. The process here, of course, depended upon the low solubility of potassium nitrate in cold water.

This ended the purification operation. If, however, the saltpetre was to be stored, it was stoved to dryness and kept in stone troughs, or sometimes in barrels.

Some idea of just how efficient this process of refinement was can be gained from a statement made in The Engineer for 29th February 1958, which in turn quotes Messrs. Able and Bloxham's Handbook of Chemistry, which asserts that saltpetre containing only one part of chlorides in

* Dowlas cloth is a coarse linen - it is nowadays used only to make teatowels.

three thousand was rejected for use at Waltham Abbey.

No information concerning the purity of saltpetre used for blasting powders can be offered. All that can be suggested is that since the purification of saltpetre looks to have been a simple and cheap process there would have been little to be gained and much goodwill to have been lost by holding short on any part of it.

The Initial Preparation of Saltpetre, Sulphur and Charcoal

Before being brought together to make gunpowder, the individual constituents were reduced to an intermediate fineness in order to achieve an even distribution of each when they were mixed.

Saltpetre coming directly from the refiners required no grinding since it was already in the form of a 'flour' of minute crystals. Saltpetre which had stood in store a while tended to compact or to re-crystallise into larger crystals. When this was so, the saltpetre was ground lightly in a small rotating mill, similar to the larger mills used to incorporate the mixed powder.

Sulphur, being somewhat harder than saltpetre, was ground in the same way as saltpetre, but was ground for a longer time.

Charcoal was required to stand for about a fortnight after it had been made because it was believed to be prone to take fire spontaneously by absorbing oxygen from the air. The initial grinding of charcoal was done, in some cases, in a ball-mill, in others, later, in a mill similar in design to a coffee grinder (a cone-in-cone set with keyed teeth and having a means of adjusting the space between the teeth). Equally, after grinding, the powdered charcoal was kept in store for about ten days before being used. This indicates that a gunpowder maker would have had to have had a considerable quantity of charcoal in reserve so long as the mill was in production.

In the case of all three constituents the powdered material was required to pass through a sieve of thirty-two meshes to the inch. Any particle which remained in the sieve was returned for re-grinding. The most commonly illustrated form of sieve was an inclined and revolving cylinder of wire mesh. These machines were always encased in a wooden cabinet with close fitting doors in order to prevent the escape of flying dust.

Weighing-up

The individual constituents, the saltpetre, the charcoal, the sulphur, were weighed with great care into individual lots, which when combined would give a weight of either 42 lbs. (19 Kg), or, in later years, of 50 lbs. (22.7 Kg).^{*} This was done by weight with scales rather than by the use of volume measures which would contain a known weight. Something of the unhandiness of the Imperial system of measurement can be seen in the way the relative proportions were resolved:

"... the proportions used at Government mills, Waltham Abbey, and also by other makers generally:- **

	lbs.	oz.	drachms	kilograms
Saltpetre	31	8	0	14.30
Charcoal	6	4	13	2.86
Sulphur	4	3	3	1.07
	42	0	0	19.07 "

The weight of an individual lot represented a single charge for the following operations of mixing and then of incorporation.

Mixing

It was at the point of mixing that a gunpowder came into being.

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- * When worked out into the proportions 75 : 15: 10, these weights will be found to be a little deficient in both sulphur and charcoal.
- ** DICTIONARY OF ENGINEERING by E. & F.N. Spon, (Ed.Byrne),p.1775, 1870.
- *** The measure being used was avoirdupois, therefore the 'carry' was sixteen drachms, and sixteen ounces.

The weighed-out materials were mixed in a copper drum. This was not a ball-mill, however. It was a drum in which the constituents could be mixed: there was no further reduction in the size of the particles. Descriptions of mixing drums are consistent:

"This machine consists of a hollow drum of copper about 2 feet (61 cm) wide by 3 feet (91 cm) in diameter, which is made to revolve at thirty-five revolutions per minute. The bearings of this drum are hollow, and a shaft passes through them, having in the interior of the drum an eight-sided boss or tube secured to it; into this a series of arms or flyers are screwed, there being on one face of the octagon and six on the next alternately, so that there are forty-four flyers altogether. They are made of flat section, but forked at the ends, and provided with holes through their flat sides, and each one is set at a different angle to the next; their points just clear the inside of the drum, and they revolve in the opposite direction to it at the rate of seventy revolutions per minute ... after the machine has been five minutes at work they (the ingredients) will be found to be thoroughly mixed."

Engineering, 18th January 1878, p.38.

When mixing was completed the gunpowder was filled carefully into bags. At this stage great care was taken to prevent the constituents from separating out according to their respective weights: saltpetre, sulphur, charcoal. Apparently the vibration from machinery especially after the introduction of steam driven plant could bring about a remarkable degree of separation.

Incorporation

'Incorporation' is the term most often used to describe the process of grinding the already well mixed constituents. It is at the grinding stage of manufacture that the gunpowder could be said to pass beyond the sort of integration which could be achieved by any hand process, without extraordinary application.

The universal practice in British gunpowder mills was to employ rotating millstones. Stamp-mills had been used in the eighteenth

century but these were not used in this country after 1772.^{*} Ball-mills, drums containing balls of heavy wood, or non-ferrous metal, which reduced the powder by the tumbling action of the balls, were much used in France and in Germany.

The incorporating mills in a gunpowder factory must by a long way have been the most expensive part of the manufacturing plant to buy, to maintain, and to power; it would moreover have been necessary to replace the stones at frequent intervals. More than any other piece of plant, except perhaps the hydraulic press, the incorporating mill could have been bought-in: identical mills can be seen in manufacturer's catalogues of the period, advertised as being suitable for milling ochre, China-clay, bones, and so on.

In design, incorporating mills changed little: in the materials of which they were constructed there was a progression from the use of wood and stone, through the use of certain metal parts, to the use of metal for all parts. A steel engraving which illustrated an article on the Waltham Abbey Mills in the Illustrated London News for 11th November 1854 shows an incorporating mill which appears to have stone millstones; the rest of the construction is clearly of wood, for it shows the wedges and pins then used to hold such machinery together. By 1878, and very probably for sometime before that, incorporating mills are shown to be of all-metal construction, free-standing, and ready to be connected to the driving bands of a remote stationary steam engine.

Minutely detailed descriptions of these later types of incorporating mills and their operation are numerous in the pages of such journals as Engineering and The Engineer. Here, however, an

* The Manufacture of Explosives by Oscar Guttman, Vol.I, p.17, London, 1895).

earlier description, taken from the article in The Illustrated London News cited above, will be given because it says more of the work of the human operatives working the mill than is usually offered:

"A pair of circular stones called 'runners' weighing about three tons and a half (3.56 tonne) each steadily and slowly roll over the powder, which is placed on the stone bed of the Mill, surrounded by a huge wooden basin; wooden scrapers follow the stones to prevent the edges of the pan becoming clogged. The powder is previously dampened, as it could not be safely ground in its dry state; about seven pints of water, called here, as by brewers, 'liquor' being added to the charge of 42 lbs. during the three-and-a-half hours of its dangerous sojourn in this mill. All possible care is taken to prevent accidents; yet from time to time these houses will 'blow' as the workmen term it. To obviate the chance of any irregularity in a clock, the water-wheel which works two of these mills ... also marks its revolution on a dial, so that the attendant can never be mistaken in the time that the charge has been 'on' - a most important point, where the over grinding of too dry powder might produce a fearful result. The chief cause of explosion has been a portion of the woodwork of the roof or mill becoming detached - such as a cog of the wheel - and falling into the pan, it would naturally act as a kind of skid on one of the runners, and produce an amount of heat, by friction, sufficient to explode the whole mass of powder. In our engraving ... small semi-cylindrical boxes are suspended under the axles of the runners, the iron collars having at times dropped into the pan; it seems strange that this precaution is of comparatively recent introduction. The risk caused by each house containing a pair of Mills is greatly diminished by the expedient of having a flat board, being suspended over each Mill: this is called the 'blow-board', and it is the first thing to move by the concussion of the air beneath it. It is connected by wires to a cistern of water, immediately over the pan of its fellow Mill; its movement, therefore, causes the upsetting of this cistern, which instantly drowns the gunpowder in such dangerous proximity. The attendants are as little in these Mills as possible; they* work in watches of eight hours each, and at the present time these incorporating-mills turn ceaselessly, except for the renewal of the charges, from four o'clock on Monday morning until late on Saturday night ... the powder thus incorporated is in hard flat lumps; and it has now to be reduced again to dust ..."

Illustrated London News, 11th November 1854, p.47.

* The 'present busy time' referred to was occasioned by the siege of Sebastopol.

Pressing

More than anything else it is the introduction of the practice of compressing the thoroughly well mixed gunpowder taken from the incorporating-mill into a truly hard cake by subjecting it to a pressure of about four hundred pounds to the square inch (137 Kg/sq.cm) which marks the difference between the 'corned' gunpowder which had come into use during the sixteenth century and 'modern' gunpowder.

Only Oscar Guttman* gives a date for the introduction of pressing into England: 1784. He does not, however, offer any other information nor does he cite any authority for his statement. Certainly the technical means for exerting a pressure of four hundred pounds per square inch - at least over a small area - had been available since the early Middle Ages.

The only method of pressing gunpowder used in the United Kingdom, for which descriptions can be found, was the hydraulic press. Of the two other methods there is no specific mention. It must be assumed that one or both of these was used before the invention of the hydraulic press by Joseph Bramah in 1795.** The most likely of these two methods is the screw-press. The screw-press, which still finds some use in workshops, where it is used for pressing out short runs of simple metal shapes, is capable of exerting high pressures, even when turned by a single strong man using the leverage of the cross-beam. A screw-press combined with a ratchet and lever (a pawl-press) could exert virtually any pressure which could be exerted by a hydraulic press.

The roller-press, which in France was called a laminoir, was essentially a powerful 'mangle' into which slightly dampened powder was

* The Manufacture of Explosives by Oscar Guttman, Vol.I, (p.204), London, 1895.

** British Patent No.2045 of 1795.

fed, sandwiched between sheets of canvas. This method must not have been much inferior to the others for compacting gunpowder efficiently because it was used on the Continent until the end of the nineteenth century.

The advantages which resulted from the pressing of gunpowder were several. The old corned powder, and the fine un-corned powder which had preceded it, had both tended to separate out in the barrel into distinct layers of the constituents, according to their respective weights. The grains of corned powder had been quite soft. Unless great care was taken in ramming home charges, in either the barrel of a gun or in a shot-hole, the corning of the grains broke up. This altered the burning characteristics of the powder appreciably, especially in the case of small arms. Pressed powder was less susceptible to deterioration through moisture. Grains of pressed powder were relatively hard compared with corned powder. Cracked under the thumbnail a grain of corned powder could be expected to fall into a fine powder; a grain of pressed gunpowder under the same conditions was more likely to break up into small, angular fragments.

The use of pressed gunpowder offered also a much greater degree of control over the rate of burning in a charge. Small grains burn quickly; larger grains burn more slowly. Since, as will be illustrated presently, the process of corning had hardly involved pressure at all, (indeed, if anything, corned powder could be said to have been consolidated by its moisture), there was likely to have been an upper limit to the size of grain which would cohere. With pressing, and the changes which could be made in the proportions of the constituents, and in the quality of the charcoal, a wide range of performance in gunpowders became possible.

Rees's Manufacturing Industry (1819-20).

A Selection from the Cyclopaedia or Universal Dictionary of Arts, Science and Literature (of Abraham Rees), Ed. A.R. Cossins, Vol. III, Published David & Charles Reprints, 1970.

But, notwithstanding the many real advantages which the introduction of the pressing process brought about, it was still only an improvement. There was nothing which pressed powder could do that could not have been done almost as well by corned gunpowder. This was affirmed by Abraham Rees as late as 1820:

"This operation, which, however, is not essential to the manufacture of perfect gunpowder, and is only performed on account of the convenience of using it in grains ... the stiff paste is first pressed into hard masses, these are put into circular sieves with parchment ... perforated with holes of different sizes, and ... connected with a horizontal wheel. Each of the machines is also furnished with a 'runner' or oblate spheroid of lignum vitae, which being set in motion by the action of the wheel squeezes the paste through the holes of the parchment thus forming grains of different sizes. The grains are then separated from the dust by sieves of progressive...

The powder described by Rees was what would earlier have been called 'corned' gunpowder. Such a powder would, it is suggested, have been of low density and thus very quick-burning: a powder for rifle or pistol.

(Since there was usually a delay between the facts as they were reported and the facts as they truly were, and because this is usually particularly the case where compiled works such as Rees's Cyclopedia are concerned, it could be that corned powder of the kind described above was not made later than the very early years of the century. The only reason why such powder would continue to be made which can be offered is that its low density would have made it somewhat more easy to ignite with the sparks falling into the pan of a flintlock. It may have been made for a time as a hand-finished luxury gunpowder. The use of the percussion lock would have made even that use of corned powder redundant).

The following is a short description of the pressing stage of gunpowder manufacture, as it was carried out at the Government mills at Waltham Abbey (Descriptions of the practice at this single mill outnumber by far those of any other, and are invariably much more detailed):

"The meal is pressed into cake by an hydraulic press. The press-box used at Waltham Abbey is a very strong oak box with gun-metal frame, 2 feet 6 inches (76 cm.) square, and 2 feet 9 inches (84 cm.) deep, so constructed that three of the sides can turn back on hinges or be screwed firmly together into a rigid box. In charging the box it is laid on its side, the top temporarily closed by a board, with only the upper side open, and a number of copper or gun-metal plates 2 feet $5\frac{1}{2}$ inches (75 cm.) square are placed vertically in the box, spaces (depending upon the kind of powder required) being maintained between them by means of two grooved gun-metal racks, removed when the box is filled. About 800 lbs. (363 Kg.) of meal is put into the box, and rammed down uniformly between the plates by means of wooden laths; the racks are withdrawn, the upper open side of the box screwed down, the box turned up so that the plates are in a horizontal position, and placed on the table of the press under the fixed press block. The pumps, which work the press in a separate house, are set in action, and the box is raised against the block until the powder has been compressed to an extent corresponding to the density required. The block is allowed to enter the box at a certain measured distance, and this means of judging the pressure is preferred to the indications of the pressure gauge on account of the varying elasticity of the meal, varying with the amount of moisture in the meal, and with the state of the atmosphere. After the charge has been compressed to the required extent (made known to the men in the pump-room by the edge of the box being made to ring a bell), the pressure is maintained for a few minutes; the box is released from pressure, removed, and unloaded..."

A Dictionary of Applied Chemistry
by T.E. Thorpe, B.Sc. (Vict.) Ph.D. et.,
London, 1891.

Granulation or 'Corning'

The laminar fragments taken from the press-plates with the aid of copper chisels are most often described as having a colour and hardness resembling that of dark slate. Ordinarily, these fragments were broken up with mallets into pieces about the size of a man's hand. Some accounts** give the surprising information that

* The time for which gunpowder is described as being under pressure varies from a few minutes to two hours according to the account consulted. The earlier accounts generally quote longer periods.

** Engineering, 8th February 1878, p.96.

when press-cake was allowed to stand for two or three days, as it sometimes was, it hardened with age so that it became difficult to break.

Granulation was the most dangerous part of the whole operation of making gunpowder, the quantity of dust generated being greater than at any other time during the entire process. It was not practicable to case-in machinery which had to be under constant inspection.

The corning apparatus used at Waltham Abbey and the larger private mills, such as those of Messrs. Hall and Son at Faversham, used machinery invented by Sir William Congreve (of rocket fame) who took out his patent, British patent No.3937, in 1815. This machinery which consisted essentially of a descending series of toothed rollers made of gun-metal, working over a series of sieves, these sieves also being kept in constant motion. The machinery broke down the press-cake into progressively smaller and smaller particles. The desired sizes of particle could be taken from the appropriate grade of sieve.

Since, again, later descriptions of the construction and operation of this kind of machinery are plentiful, an earlier process will be given as an example. This was the granulating process as it was carried out at the Elterwater Gunpowder Works in Cumberland in 1878. However, it was, even at that date, considered to be somewhat old-fashioned. It is representative, perhaps, of the plant and practice for making cheap grades of mining powder on a relatively small scale; that is to say on a small scale relative to, say, the Faversham Gunpowder Works.

"This machine in the corning house, used for breaking the press-cake into grains, was one of the old-fashioned corning machines, consisting of a frame of wood suspended from the ceiling, and made to oscillate by means of a perpendicular crank passing through the floor. In this machine a number of wooden sieves lined with copper and containing pieces of press-cake and round blocks of lignum vitae placed upon the frame are shaken violently by the motion of the crank, and the blocks dashing about in the sieve soon reduce the press-cake to fragments and dust which soon pass through the sieves to the floor.."

The reason for so primitive a machine being used at so late a date was probably that the cost of the more modern plant was prohibitive, that the old plant worked well enough for the quality of the powder it was making.

The plant at Elterwater, as at many of the other Lakeland mills, was water driven. It could thus well have been the case that the power available from the water wheels was not sufficient to overcome the friction in the gear trains which can be seen, in illustrations, to have connected the rollers of machines of the Congreve type together.

As with the Congreve machine also, the amount of dust caused by the breaking down of press-cake was large, and the danger at this stage of manufacture must have been equally great. Moreover, unless there was an outlet for quantities of very fine grained powder of low, blasting, quality, the proportion of any mill-charge which needed to be re-pressed must have been appreciable.

The magazine The English Mechanic for May 1856, in a popular article on gunpowder manufacture, gives some idea of the allowances which had to be made for such losses. In order to make one hundred pounds (45.4 Kg.) of finished gunpowder, 77½ lbs. (35 Kg.) of saltpetre, 10½ lbs. (4.8 Kg.) of sulphur, and 16 lbs. (7.26 Kg.) of charcoal were needed. This amounted to 104 lbs. (47 Kg.), or to a wastage of about 3.8 per cent. As might be supposed the loss of charcoal was greatest. One of the main changes in practice brought about by the Explosives Act of 1875 was the requirement that gunpowder dust should be swept from all surfaces inside the breaking-up rooms daily.

Polishing, Dusting and Glazing

The 'foul-grain' gunpowder coming from the sieves of the granulation machine had first to be freed from dust. This was done

by passing it through a dusting reel. A common description of a dusting reel is that of a cylindrical, sometimes octagonal, wooden framework, about eight feet (243 cm.) long, and one and one-half feet (46 cm.) in diameter, covered with copper wire gauze of twenty meshes to the inch (2.54 cm.), and set to a slight incline along its axis of rotation. In order to catch the shed dust the reel was enclosed in a light wooden cover.

Powder was passed from the high end of the reel to the low continuously. A single passage along the reel, which was rotating at the rate of 40 r.p.m. was sufficient to clear the foul-grain of dust.

The term 'polishing' does not accurately describe the second part of the finishing process. It is true that the grains did take on a polish. But the operation would be better described as 'rounding'. Granulation had produced not so much grains as angular fragments - these had to be rounded off by being subjected to a light degree of mutual attrition.

All polishing machinery was based upon a rotating cylinder of some kind. At its simplest, a polishing drum might be little more than a single cask fitted internally with a few square-sectioned tumbling bars. The machinery at the Government mill, or at the larger civilian manufactories, may have been built with more care, and worked in batteries, but it was essentially of the same design.

Gunpowder grains had been polished before the practice of pressing and the subsequent breaking down stages of manufacture had been introduced. The process was well tested.

Polishing was a slow process. Cheap blasting powder was worked for only a few hours; good quality sporting powder took four to five hours, and could be given as much as ten hours, at forty-two revolutions to the minute. The long polishing afforded to sporting powder gave it

a glaze which was described as 'brilliant'. If, however, in the case of blasting powder, it was intended to use graphite to enhance the glaze, it was at the end of the polishing stage that it was put into the drum. The usual amount was half an ounce (2.84 gram) to every hundred pounds of gunpowder.

On the subject of the addition of graphite to gunpowder, a theory is offered here.

It is suggested that the practice of adding graphite to large grained mining gunpowder began in the Lake District gunpowder mills. The polishing part of the making of gunpowder is, as we have seen, lengthy. It is, therefore, costly in terms of not only time but of energy. All of the early machinery and much of the later machinery depended upon water-power. In Summer the supply of water to the water wheels was likely often to have been unreliable. Polishing is a finishing process: it is desirable, even in mining powder, but, and especially in mining powder it is by no means essential. Where there was a need to make a large quantity of powder in some haste, and where at the same time the supply of motive power was uncertain, the polishing of the grains is likely to have represented a bottle-neck in production. This would have been particularly the case at a small mill where all of the machinery could not be worked at the same time. The need was to achieve the same appearance without the same expenditure of time and power. Graphite nodules occur in Borrowdale. The addition of a little graphite may have begun as a sharp - but necessary - practice. In that the graphite slowed the rate of burning in the powder it may not have been an absolute fraud.* It can be imagined that the practice remained a secret within the trade for a very long time.

After being polished, the gunpowder was passed once more through a dusting reel to remove any fine dust formed during the polishing.

* Oscar Guttman in his later book, Twenty Years Progress in Explosives, (p.8), London 1912, expresses the opinion that residual dust '... affects the quality of the powder by closing the pores.' (my italics). Graphite would have the same effect; it is also relatively inert.

Drying

Drying was the final operation in the making of gunpowder. Early accounts state simply that the powder was spread in shallow trays set around a room in which there was a 'gloom stove'. A gloom stove was a large copper dome with a fire burning underneath it. The fire had no direct access to the drying chamber; the heat passed through the sheet of copper. Drying by this method could take several days.

Later accounts give much more detailed descriptions. Steam heated rooms came into use after about (so far as can be determined) 1860. At the height of their development, these were double-glazed rooms fitted with large bore, cast-iron, steam pipes. The gunpowder was spread in wooden trays with canvas bottoms at the rate of about seven pounds (3.18 Kg.) weight to the tray. The trays are described as being of dimensions three feet (91.5 cm.) by two feet six inches (76 cm.) by one and one-quarter inches (3 cm.) deep. A stoving room could, in about eighteen hours, dry the equivalent to forty barrels of powder.

Where steam power was the prime mover in a factory the drying rooms may not have been a heavy charge because some of the waste steam from the main boiler could be used.

Drying required some care. Too rapid a drying could cause the powder to effloresce and large grains to crack.

Drying always caused the powder to shed residual dust. When drying was completed the powder was given a final pass through a dusting reel before being put into barrels.

Magazines, Storage and Handling

Very little material which gives much information about the storage of civilian gunpowder can be offered. It is almost as though once gunpowder had left the maker's premises it became just another 'article of commerce', a commodity to be transported without special

consideration. Certainly this appears to have been the case with the gunpowder which blew up on its passage along the Regent's Canal in the great disaster of 1874.

"The cargo consisted of sugar and other miscellaneous articles... and some two or three barrels of petroleum and about five tons of gunpowder. It is stated to be common practice to send gunpowder and petroleum in the same barge. Most of the gunpowder was in barrels, but there was one box which was probably filled with powder in canister or in flasks. The powder was consigned by Messrs. Pigou and Wilkes to Chesterfield for Codnor Park near Nottingham, and was sent for blasting purposes. It had been manufactured at the Waltham Abbey Mills at Essex."

The Illustrated London News,
10th October 1874. p.350.

It was not only the custom to transport gunpowder with other goods but also to store it with them. The enquiry which followed the Great Fire of Newcastle in 1854 was unable to establish the cause of the tremendous explosion which followed upon the outbreak of the fire. Briefly,* there was on the Gateshead side of the river Tyne a large warehouse, known as Bertram's Warehouse, which was used as a free (i.e. not a 'bonded' warehouse) by local merchants. The warehouse was divided up into flats, that is to say floors, and the flats were again divided up into lock-ups. The contents of any merchant's lock-up were entirely his own concern.

Accounts of the explosion are compatible with the presence of a large quantity of gunpowder. A cargo of one hundred and forty tons (142.24 tonnes) of mining powder which had come into the port was not fully accounted for. The testimony of the merchants who had rented the lock-ups was rather solidly against there having ever been any gunpowder in Bertram's Warehouse, but the persistence of the rumours that powder had been stored there was so strong that a special enquiry

* A Record of the Great Fire of Newcastle (to which is prefixed a History of Newcastle) etc., G. Routledge (Pub.), London, 1855.

was instituted.

The example of the Newcastle Fire shows that it was quite possible for explosives to be stored more or less anonymously with thousands of tons of other commodities, and close to a busy centre of trade, without there being any serious regulation or control.

The kinds of magazine and powder stores existing can be guessed at with some confidence by considering the probable final distribution of manufactured gunpowder.

Naval and military magazines were doubtless the best managed. No record of any military accidents can be found in any of the material examined.

Manufacturers' 'holding' magazines, such as those at Erith and Purfleet, and including also the 'powder-hulks' moored off-shore in the Medway used to store powder made at the mills, which were as much as thirty miles (48 Km.) away, and awaiting shipment to customers.

Export magazines, such as those at Wallasey* and Glasgow, were usually managed by Port Authorities and offered safe storage to the owners of explosive cargoes. These may have been the biggest holders of gunpowder, in terms of sheer tonnage stored at any one time, that there were.

Wholesalers' stores were simply the stores used by merchants to store powder before breaking bulk for the retail trade. Retailers' stores will be referred to at several points in this study: gunpowder was for many years before the 1875 Act sold as readily as tea.

Colliery and Quarry powder stores held the low quality gunpowder which was usually sold to the men in order to help them win the coal or stone which was paid for by 'the piece'.

* The Times, 30th June 1851, 2a 5e.

The extreme care which was taken in the manufacture of gunpowder can be contrasted with the carelessness with which it was handled in everyday use. The first of the two following quotations gives the procedure carried out at the Waltham Abbey Mills. This approximates to the sort of care taken aboard men-o-war when powder was being handled.

"Before entering this house we are required to encase our feet in goloshes innocent of nails; and the greatest care is taken that the stranger's own boots shall not touch the platform in front of the Mill proceed to the 'Mixing-house' where every precaution is needed. Around the room there is a hoop some two feet (61 cm.) high; at its side kneels a workman, who fits a pair of overshoes on your feet, carefully placing each, as it is covered, within the charmed circle: here a sense of danger first strikes you, for you are actually walking, or sliding about, in gunpowder ..."

The Engineer, 11th November 1854

This is set against the suicidally lax management of some civilian gunpowder stores:

"It is quite true that in some - perhaps many - instances, due precautions are observed with regard to the storage of gunpowder; but Major Majendie's returns of inspections prove lamentable deficiency and gross carelessness to prevail in the great majority of cases. In some cases the officer has been conducted to magazines situated in densely populated neighbourhoods, where he has been the somewhat reluctant witness of powder being shovelled out of a barrel with one hand whilst a candle was held with the other. His reluctance to remain on the spot was probably not diminished when, on the candle being blown out by a gust of wind, the worthy proprietor produced loose matches from his pocket, with which he relit the candle."

Report to Select Committee of the House of Commons, Reprinted in Engineering, 22nd May 1874, p.374.

A major explosion of black gunpowder at Belvedere near Erith, in Kent, on the morning of Saturday 1st October 1864, brought both public and official attention to bear upon the dangers inherent in the transportation of large quantities of gunpowder. A detailed account of the event with steel-engravings and diagrams can be found in

The Illustrated London News for 8th October 1864 (p.365).

The explosion was thought to have occurred while barrels of gunpowder were being transferred from a magazine building to barges, via a jetty. The magazine building, one of several along the same waterfront, was described as being 'a substantial building about 50 ft. (15.24 m.) square, and consisting of two floors.'

The explosion itself cannot concern us here, but the testimony given afterwards says much of the procedures and precautions which were supposed to have prevented such explosions. The protestations of extreme care were not borne out by later evidence; consequently, the descriptions of what safety precautions were taken must be seen as representing an ideal which was not nearly achieved:

"The Transport and Storage of Gunpowder. - The following regulations to be observed by masters in charge of barges, etc., in the Thames, Medway, and Orwell, and canals adjoining, were last week issued at Woolwich by order of the Naval Director-General of Stores, Captain Caffin, C.B., A.D.C. to Her Majesty. They set forth that - - 'Whenever barges or other craft belonging to, or engaged by, the military store department are employed in conveying gunpowder ... the following rules are to be observed.

With regard to fires or lights on board:

1. No fires are to be lighted on board any barge ... conveying gunpowder ... to any place in the River Thames...
2. When the barge ... is one mile (1.609 Km) below Gravesend, and not nearer than half a mile from any inhabited place or magazine, fires may be lighted on board for cooking purposes only.
3. No barge having powder on board is to remain alongside the jetty ... of any magazine during the night ... nor at any time (day or night) except when actually employed in the operation of embarking or disembarking powder ... but is to haul off and anchor...
4. No barge having powder on board is to be left without having a responsible watchman in charge.
5. With regard to the sailing and riding lights required to be carried according to Admiralty regulations, the usual tinder-box etc. will be used ..., and under no pretence are lucifer matches to be on board. Smoking on board is most strictly prohibited.
6. ... hatches are to be carefully covered with tarpaulins ... not to be removed until the cargo is ready to be discharged.
7. A powder flag must be kept flying ..."

The Engineer, 25th November 1864, p.327.

And again,

* The powder flag was almost certainly the red swallow-tail flag, the 'red burgee', which was later adopted to signify the letter "B", 'I am loading or discharging explosives' in the International Code of Flag Signals.

"A code of instructions, drawn up for the guidance of foremen and others employed aboard the floating magazines off Woolwich, has likewise been read and signed by every person engaged there and all persons have been given to understand that the slightest breach of the regulations, or any dereliction of their ordinary duties, will be punished with instant dismissal. No person to enter the magazine ... without changing his shoes for the proper slippers ... labourers employed in working magazines or removing powder from vessels, are not to carry knives or other objectionable articles, and are to wear the dresses that are in future to be provided for their use. The foremen are to see that the magazines are carefully swept with a hair broom after every day's work, and take care that a proper supply of hides, wadmiltits,* and mats is in readiness and use during the removal of powder..."

The Engineer, 25th October 1864, p.

And finally,

"... it is probable that tires (sic) of vulcanised rubber to the wheels running on wooden rails would be better than tires of copper, and wheels running in timber grooves with water trickling down them would be better than edge rails."

The Engineer, 14th October 1864, p.239.

There were designs for fireproof magazines which were to hold the small quantities of gunpowder stocked by retailers. One such design was tested at Plumstead Marshes by the makers, Messrs. Milner and Co. of Liverpool. In its essentials, the small magazine resembled a safe with double walls; the space between the walls were to be filled with 'a non-conducting and vapourising composition'. A prototype resisted a surrounding coal fire for more than six hours. The journal Engineering for 11th October 1872 (p.258) devotes a long article to the trials of this magazine.

The difficulty with such safety precautions, then as now, is likely to have been the high initial expense.

* 'wadmiltits', this is almost certainly a literal transcription of 'wadmaltits': wadmalt, a thick woollen cloth; tilt, awning for waggon or boat. See Chambers Twentieth Century Dictionary (1909).

The Qualities of Good Gunpowder

Black gunpowder was a commodity of such importance, and of such general experience, that it was important that anyone having anything to do with it should be able to tell sound gunpowder from bad. The numbers of people who, a hundred or more years ago, would have had cause to handle gunpowder for one reason or another would have been very many times larger than the number of people who today would have occasion, or opportunity, to handle explosives.

Moreover, since gunpowder was usually sold 'loose', people literally did handle gunpowder. There is not a precise equivalent in present day living because explosives are strictly controlled by legislation. But, to offer an analogy, the householder of a hundred years ago would have a knowledge of the care of a draught animal and a cart, he would be able to tell good feed from tainted; in the same way, the modern suburban dweller often has a great deal of knowledge of the motor car. The need to be able to judge a sample of powder was important enough for a list of the appearance of good and bad gunpowder to be printed often in general works from Abraham Rees' Cyclopedia of 1820 to Crookes' translation of Wagner's Handbook of Chemical Technology, and other works of even later date. The Rees prescription gives the strongest impression of first-hand acquaintance:

- "There are several ways of proving the goodness of gunpowder.
1. By sight; for if it be too black, it is too moist, or has too much charcoal in it; so also if rubbed upon white paper, it blackens it more than good powder does; but if it be a kind of azure colour, somewhat inclining to red, it is a sign of good powder.
 2. By touching; for if in crushing it with your fingers' ends, the grains break easily, and turn to dust without feeling hard, it has too much charcoal in it; or if in pressing it under your fingers upon a smooth board, some grains feel harder than the rest, or, as it were, dent your fingers' ends, the sulphur is not well mixed with the nitre, and the powder is bad. And also by thrusting the hand into a parcel of powder, and grasping it as if you were about to take a handful of it, you may feel it to be dry and equally grained, by its evading the grasp, and running

mostly out of the hand.

3. By burning, in which method little heaps of powder are laid on a white paper three inches (7.62 cms.) or more asunder, and one of them is fired; which, if it fires all away, and that suddenly and almost imperceptibly, without firing the rest and makes a small thundering noise, and a white smoke arises in the air almost like a circle, the powder is good; if it leaves black marks, it has too much charcoal, or is not well burnt; if it leaves a greasiness, the sulphur or nitre are not well cleansed or ordered. Again, if two or three corns be laid on paper an inch distant, and fire to be put to one of them, and they all fire at once, leaving no sign behind but a white smoky colour in the place, and the paper not touched, the powder is good..."

The above is a fair sample of the advice offered by Abraham Rees - there is much more. Later caveats about determining the quality or otherwise of black powder offer less advice about defects which might have come about as a result of faults in the manufacture or the original purity of the ingredients of a black powder and more on indications of deterioration in what had been well made but badly managed.

There was a good knowledge of gunpowder's tolerance of ambient moisture - the limits beyond which it was held to be spoiled:

"Gunpowder can absorb more than 14 per cent of moisture from the air; if the quantity of water thus taken up is not above 5 per cent, the powder, on being gently dried reassumes its former activity; but if the quantity exceeds that amount, the gunpowder will not burn off rapidly, and when dried single grains become covered with an efflorescence of saltpetre..."

Wagner, Chemical Technology, 1856, p.152.

The Gunpowder Barrel

Virtually the only container for the bulk holding of black gunpowder which enjoyed any extensive use was the wooden barrel or keg. And yet the literature contains very few references which give any specific information about the barrels which were used to store gunpowder. The probable reason for this was that barrels were then such a part of everyday experience that it was not thought necessary to offer any description. However, since such knowledge is no longer general, and

because it is wished to show something of the importance of this container to the storage, handling, and transport of gunpowder, it will be useful to review, very briefly, its main characteristics.

The structure of a barrel is akin to that of an arch: the edges of the staves are bevelled toward each other like the voussains forming a stone vault. Internal strength is dependent upon external pressure. In the barrel, the external pressure is supplied by the enclosing hoops. If the hoops are removed, a barrel can be reduced to its staves and head-pieces, something which was ordinarily done when empty barrels were being returned. The peculiar shape of the barrel, which does not give the most economical stowage possible, derives from the need to have a shape which will allow the hoops to be driven home with an increasing tension. It is this shape which allows a barrel to be steered as well as rolled over any reasonably even surface, and, with the necessary ropes and a little skill, a very heavy barrel can be parbuckled up and down steeply inclined planks, as into a ship's hold, with an astonishing gentleness.

To return to the specific topic of those barrels which were used to hold gunpowder, the main observation which will be made is that the quality of the barrels used reflected very clearly the value of the grade of powder they were to contain. Only two direct references to the kind and quality of barrels used for holding gunpowder can be cited. The first gives an indication of gunpowder barrels at their best; the second at what must have been quite their worst.

Oscar Guttman* devotes five pages to the description of the containers used to hold gunpowder. But his account is almost entirely of continental, military, practice. His only reference to British usage is given in the short paragraph:

* Guttman: The Manufacture of Explosives, Vol.I, pp.260-265, London, 1895.

"In England, powder is placed directly into barrels holding 100 lb. (45.4 Kg.) Since these barrels are made so carefully, the use of a linen bag (as a liner) is considered unnecessary ... the barrels were only filled to 9/10ths of their capacity, since it was believed that by rolling the barrel the powder was prevented from caking. For this purpose the barrels were rolled every year over a copper plate on the floor of the magazine."

Here, again, Guttman is almost certainly referring to the military practice.

Military explosive handling is usually less prone to accident than civilian. The reasons why this should be so are not difficult to guess. Long before the nineteenth century there were directions for the proper management of magazines - these were prescriptive regulations. The personnel acting according to such instructions are likely to have been specialists. Above all, military labour is usually plentiful and is a standing charge, so that it matters little how much time and effort is put into magazine fatigues. Also the throughput of military powder, into and out of magazines, was, during the long peace after 1815 and again after 1856, relatively small. Guttman is above speaking in terms of a barrel of gunpowder remaining in store for more than a year.

Civilian gunpowder barrels can be shown on at least one occasion to have been very inferior containers. The following testimony which was given at the enquiry which followed the Erith Explosion of 1864 shows what stood at the opposite extreme to the careful packing expended on service powder.

"Indisputable evidence in the handwriting of the poor fellow Raynor, in the form of a letter, was wafted away by the explosion at the instant of death, and was produced at the Coroner's Inquest ...

It is a letter signed Geo. Raynor, for J. Hall and Sons, and directed to Mr. Monk:- 'Sir, - for some time past I have witnessed the leakage of casks to a very great degree. * In fact, it amounts to this - the majority of the quarters in

* 'quarters' refers to barrels holding a quarter hundredweight of powder: twenty eight pounds Imperial, 12.7 Kilograms.

particular are not fit to put gunpowder in, not only with the f.f.f., but the f.c.o. and the B.C. In fact the hoops are falling off the casks as they are being handled, and the heads fall in. I have not complained to anyone else, but if this growing evil is not remedied, I must of necessity do so to someone else. It appears the wood is not properly seasoned, so the workmanship must be very inferior. I hope you will do something to alter this, as we must get them within reasonable bounds. I can drive the hoops so as to get another on in many cases. Your attention will oblige, yours truly - Geo Rayner."

The Engineer, 14th October 1864 (p.239).

As foreman of a civilian magazine, the unfortunate Mr. Rayner had none of the luxuries allowed to his military counterpart. As will be shown in more detail* elsewhere in this study, the gunpowder trade was as much a profit-maximising industry as any other during the nineteenth century. It can be noted particularly that the firm concerned was J. Hall & Sons, one of the largest and most successful of the powder manufacturers.

It is because gunpowder making was an industry organised in much the same way as any other of the time that it is possible to offer a possible explanation for the apparently appalling mismanagement at Belvedere.

Cheap contents warrant neither the use of expensive barrels nor the setting up of a return and re-fill organisation. The losses to the manufacturer are least if the container is considered to be a once and for all part of the price of the contents. Good barrels would simply not have been returned; and to have introduced a system of deposits against return would have increased the probability of the empties being pilfered. A return system also requires that a manufacturer own rather more than twice as many barrels as are actually in transit and full.

(In the wine trade, where the barrels were often worth much more

* See Gale's Gunpowder and Neumeyer's Gunpowder.

than their contents, the return of empty barrels had been well organised from the Middle Ages onwards).

Blasting gunpowder, because it was the cheapest grade of gunpowder, no doubt was packed into the worst barrels. It is also probable that, because mines and quarries were often remote, barrels holding blasting powder were subject to more stages of trans-shipment than other more expensive powders.

A Note on the use of Withes

The modern notion of a barrel is most likely to be drawn from experience of beer 'in the wood' where the barrel is hooped with iron. And where a barrel has to hold the relatively large weight of liquid contents this was also the case during the nineteenth century. But for many purposes, especially for gunpowder barrels where the use of iron or steel was prohibited, the withe (withy), a hazel or willow sapling split longitudinally and used with the bark left on, was by far the more common material for barrel hoops. A close inspection of the fine detail on steel engravings of the time shows this to be so.

Operatives in the Gunpowder Industry

The work people who actually made the gunpowder are almost entirely anonymous. Only when they were the subject of a coroner's jury were these men and women accorded their names. Generally speaking, the earlier the year the greater the likelihood there is of there being any record of an individual.* Occasions for the recording of anecdotes no doubt became fewer as the century advanced and the trade became larger and more impersonal.

If the risk of being blown to pieces of hideously burned in one

* See The Faversham Gunpowder Industry Pts. I and II by Arthur Percival, Industrial Archeology, 1968, Vol.5, No.1, et. seq.

of the periodical accidental explosions is set aside, gunpowder making does not appear to have been incidentally dangerous, nor was it very arduous. No occupational diseases are associated with the work.* And this is reflected in the relatively low wages paid. In 1859, many workmen were paid as little as two shillings and three pence per day; a few were paid four shillings. This is less than half of what was paid to such craftsmen as carpenters and bricklayers at that time.**

The Export of Gunpowder Mill Machinery

The machinery used in all the stages of gunpowder manufacture was adapted from designs which were capable of a number of alternative industrial applications; and as such, gunpowder-making machinery entered freely into a large export trade in industrial plant.

The possession of a modern gunpowder mill looks to have been as much a matter of prestige and strategic need to a new nation in the nineteenth century as a home arms industry is today. There is a close correspondence between the announcement of a contract for the supply of a new powder mill and some major political change in the affairs of the customer nation.

Following the conclusion of the Crimean War, the firm of Messrs. Galloway of Knot Mill, near Manchester, contracted to build a large gunpowder mill for the Ottoman Government:

"These mills are to be driven by a 60 horsepower condensing engine, which is also at present in hand. Each of the mills has two edge rollers, weighing 13 tons (13.2 tonnes) the pair. To prevent the explosion of one mill communicating with another, they are each placed 70 feet (21.3 m.) apart, and, as they are

* The gunpowder trade is not mentioned at all in 'A Treatise on Hygiene and Public Health' by T. Stevenson, M.D., F.R.C.P., and Shirley F. Murphy, Pub. J. & A. Churchill, London, 1890, which lists literally hundreds of complaints suffered by the workmen in almost as many trades and occupations.

** The Engineer, 3rd June 1859 (p.389).

all driven by the same engine, there is a continuous line of heavy wrought iron shafting, extending underground to the distance of 240 feet (73 m.)."

The Engineer, 4th July 1856, p.356.

The firm of J. & H. Gwynne of the Hammersmith Ironworks, London (The Company is still in existence), had, before 1870, manufactured and sold all the machinery necessary for the setting up of a gunpowder mill for the Japanese Government. The exact date of the contract cannot be cited, but it would appear to coincide approximately with the establishment of the new Japanese capital at Tokyo. The machinery was to be driven by 'cattle-power'.

A somewhat larger mill, along with the water turbines to power it, had already been built for the newly independent kingdom of Italy.

A more extensive search would doubtless show many other examples.

(From the maker's nameplates showing on illustrations of plant dating from later in the century - after about 1875 - it would appear that German machinery was pre-eminent in gunpowder mills).

'Trade Gunpowder'

A little better than blasting gunpowder in general quality, but decidedly well below all other gunpowders, there is in the literature an occasional and invariably a pejorative mention of 'Trade', 'Exportation', or 'African' gunpowder. This was made almost exclusively for sale in Africa, and particularly in West Africa.

(It can be observed that where Europeans came into contact with peoples who had already a knowledge of gunpowder, as in India and China, there was little demand for 'Trade' powder. There was often, however, a ready appreciation of good quality European made gunpowder).

* and ** Dictionary of Engineering by E. & F.N. Spon (Ed.Byrne), London, 1870.

The extent of the trade, especially before colonisation began in earnest after about 1870, was very considerable. But this was a product made for buying and selling only. It was by all accounts very inferior stuff. The naturalist French-American, Paul B. Du Chaillu, in his book* gives his impressions of 'Trade' gunpowder:

"Wherever I have been among them my shots have excited astonishment; this is not so much because my guns are better, as because I have good powder, and they do not know how to load a gun. The negro idea is to put in as much powder as he dares, and on top of this as much old iron as he can afford to throw away in one shot. If the powder was only of average strength they would blow themselves to pieces, but the traders on the coast make it mild by adulterations; and I have actually seen bits of iron of various shapes rammed into a gun till it was loaded to within inches of the muzzle. Consequently the recoil is very heavy; they dare not hold the guns to their shoulders..."

Nor did this departure from the usual high standard of British made manufactures go unnoticed. In a report on the work of the Government controlled powder mills in France, which appeared in The Engineer for 18th February 1858, there occurs the following sentence:

"It appears from a comparative trial that it (French powder) is greatly superior to that of which samples were sent to the War Office by Mr. Regis of Marseilles, as some of the gunpowder given in exchange by English traders on the coast of Africa."

From the above it might be deduced that not all 'Trade' gunpowder was British made, and that, free trading allowed, 'good' gunpowder would tend to drive out bad. Vast stocks of surplus gunpowder remained at the end of the American Civil War (1861-1865) to depress the gunpowder market for some fifteen years afterwards.** The existence of such stocks may have done much to reduce the making of poor quality powder.

It is of course unlikely that any of the usual sources would

* Explorations and Adventures in Equatorial Africa, by Paul Du Chaillu, Pub. T. Werner Laurie, Ltd. London, 1861 (p.107).

** The Chemical Industry during the XIX Century, by L.F. Haber, Oxford, 1958.

include specific descriptions of how powder of a markedly inferior quality could be made. It is possible, however, to glean a little information about the ways in which 'Trade' powder differed from the more respectable varieties.

'Trade' gunpowder was commonly much blacker in the grain and very much more highly polished than even the highly glazed English gunpowder. In a general article on gunpowder which was printed in The Engineer for 14th June 1867 (p.534), the following comment about the cosmetic finish applied to such powders was made.

"Occasionally the polish of gunpowder grains is heightened with blacklead (powdered graphite), a practice which prevails in the manufacture of gunpowder for the African market. We need not indicate that the presence of blacklead, in whatever quantity, is undesirable; being wholly incombustible it necessarily tends to increase the residue of fouling.

It may be that the high polish brought about by the use of graphite was desired not because it appealed to the users' aesthetic sense, but rather because it at least made the adulteration spoken of by Du Chaillu more difficult to bring about.

It is suspected that gunpowder intended for the African trade was more, perhaps much more, dense than other powders. There is little direct evidence to support this suspicion. Oscar Guttman gives a gravimetric density (the weight of a given quantity of gunpowder filling a specified volume) for a French gunpowder which he classifies as 'Exportation powder' of a value 0.970. This is set against a value of 0.860 for sporting gunpowder.* The suspicion is based upon a consideration of the advantage to be gained by the manufacturer and the merchant from the practice.

The press-cake stage of gunpowder making must have been quite the most economical part of the whole process, because it required motive

* Guttman: The Manufacture of Explosives, 1895, p.288.

power for a very short time, and the powder was under compression for only a matter of minutes. A hard-pressed powder was likely to have given off less dust than less dense powders. There would consequently be less of each batch to re-process.

The slower rate of burning which hard-pressed powders gave may have been a necessary complement to the quality of the 'Dane guns' in which it was to be used.

If it was the case that 'trade powders' were commonly made in the form of exceptionally dense grains, it could be that the demand for this sort of gunpowder grew from no motive of sharp practice at all - it may have been that there was simply a need for a product which could withstand casual handling during the successive transactions of up-country retailing.

Trade gunpowder was made in quantity at the mills which made civilian blasting powder. The mills of Westmorland and Furness were responsible for about half of the country's output of this kind of powder. However, earlier in the century, at least some inferior powders were made at the Government Works at Waltham Abbey, for in a description of the works published in The Engineer for 29th October 1858, (p.335), it is stated that 'very coarse, and coarse-grained powder, blasting powder, and some kinds of foreign rifle powder, are occasionally glazed with graphite'.

It is entirely possible that service gunpowder which had been long in storage or which had deteriorated in some other way so that it no longer came up to the required standard may well have been sold off to civilian buyers for some form of partial re-processing and subsequent re-sale for the African market.

Contraband Gunpowder

Not all gunpowder was factory-made, nor could it all be State-controlled. It is important to show that gunpowder was not susceptible to any absolute embargo. Long after the manufacture of gunpowder became a highly complex process, European troops were being bested by oppositions using gunpowder ground between two stones by their womenfolk. It may indeed only have been after the middle of the eighteenth century that in quality European gunpowder became materially superior to that made in Asia. Even in Europe, and as late as 1853, some gunpowder was being made without the aid of machinery:

"In Spain, the public gunpowder manufacture is a government monopoly, and the article is both dear and bad. Hence the peasants have long been stimulated into the preparation of their own. The operation is carried out with great secrecy, just as illicit distillation in the wilds of Scotland and Ireland, and subject to frequent interruption; yet the result is by no means despicable, as I have often proved. The chief defect of this powder is softness of grain, but it ignites with great facility, and fires with sufficient rapidity in a percussion gun to answer all common purposes. Having secured the confidence of a gentleman of uncertain profession, who spent a great deal of his time amongst the mountain passes leading from Salobrena and Almunecar, armed with a blunderbuss for defence, it is supposed, the writer of these pages was favoured with a private inspection of the domestic powder manufacture. A mortar was employed for braying the three components together, moistened with water, and the half dry paste was grained by pressure through a sieve; no preliminary compression having been employed, and hence the softness of the grain."

Projectile Weapons of War and Explosive Compounds,
by John Scoffern, M.B. London: Cook & Whitley,
1852. 2nd Edn. April 1853, p.159.

So far as can be determined there was no special attempt to levy taxation upon gunpowder in the United Kingdom: there was, therefore, no motive for illicit manufacture. In France where production was a Government monopoly there was an attempt to regulate the use to which the various grades of gunpowder were put by altering the proportions of the ingredients used. Engineering for 18th August 1870 mentions that the French Government was doing what it could to discourage the use of mining powder as a propellant in sporting guns by increasing the proportions of both sulphur and of over-burned charcoal.

Compressed Black Gunpowder

Without known exception all of the compressed gunpowders which were the subject of experimentation and trial between 1870 and 1878 were common black gunpowder of the traditional British formulation.

The chief representative of the few compressed black gunpowder mining explosives which were essayed was E.S.M. (Extra Strong Mining) powder, which was made by Messrs. Curtis and Harvey.

(The most extended discussion, almost the only contemporary discussion, of this explosive which it has been possible to consult is Frederick Augustus Abel's 1880 paper, 'Explosive Agents applied to Industrial Purposes'.* It is hard not to conclude that this form of gunpowder was the subject of so much discussion because it was a vehicle for a more extended quarrel which went on over many years and with some acrimony between Abel, as the gun-cotton producers' agent, Mr. Orlando Webb, who was a friend of Alfred Nobel and consequently a partisan for the nitro-glycerine explosives, and Mr. Andre, who, if he was not an active supporter of the gunpowder trade,** was at least ever ready to counter, usually with some incisiveness, Abel's scathing attacks.

We can only be grateful that these men chose to air their prejudices before their peers at the Institute of Civil Engineers, for in doing so they strove to bring into recall incidents and facts that otherwise would not have been recorded).

E.S.M. was Curtis and Harvey's response to competition. It was the firm's attempt to upgrade its product to meet competition from the powerful new explosives which were beginning to take over some of the work which had always been done by black powder. The competition was in an area where, in terms of the weight of explosives used - in blasting explosives - it was most telling.

Commercially, the gunpowder trade was well able to cope with competition from the producers of either gun-cotton or dynamite than these were able to compete with it. They were, as will be discussed

* (Paper No.1712). 'Explosive Agents Applied to Industrial Purposes' by F.A. Abel, F.R.S. etc., Proceedings of the Institution of Civil Engineers, Vol. LXI, 23rd March 1880.

** Mr. Andre was well enough known later to the 'Curtis' of the gunpowder firm, Curtis and Harvey, to be with him joint patentee of an explosive called 'Amberite'.

presently, in competition with each other. The gunpowder trade - in which Curtis and Harvey was by 1870 foremost - was well established in both its markets and its technical reputation. Both gun-cotton and dynamite had suffered long periods during which they were thoroughly discredited as being too dangerous for use.

It was in its chemical constitution that gunpowder had virtually reached its limits. If long experience had indicated that there was unlikely to be any extension of gunpowder's powers, increasing chemical knowledge was to confirm it. The firm, no doubt because of its large fixed investment in gunpowder making plant, turned to the only two innovations which they might apply without their having to change the essential nature of the gunpowder they produced. The idea was to pack more gunpowder into a blasting cartridge than had hitherto been the practice, and to cause that gunpowder to explode more violently than ever before. The two means whereby this was to be achieved will be considered in turn.

By about 1860, mechanical engineering technology and metallurgy applied to the making of heavy artillery pieces had leaped ahead of the chemical knowledge available for the production of suitable propellants. There was a need to find a propellant which would place less stress on the barrel of the gun, while at the same time maintaining the initial velocity of the shell. For a time the answer seemed to lie in the use of very large grains of gunpowder pressed to an extreme hardness. The work was begun in the United States by General Rodman and Dr. Doremuss. There was a general interest in such compressed gunpowders by all the major powers. In the United Kingdom these powders were produced at both the Waltham Abbey mills and by Curtis and Harvey at Hounslow.*

* Material concerning the introduction of 'pebble' and other very large grain gunpowder belongs properly to the history of military technology and cannot be treated here other than to use it to support certain deductions to be drawn from the material, incidentally. Good extended accounts of the manufacture and testing of these special powders can be found in: The Engineer, 16.2.70, p.183 et seq.; Engineering, 31. 3.71, p.211 et seq.; Chemical News, 1. 9.71, p.101 et seq.

The essentials of the idea were given in an article which appeared in The Engineer for 18th January 1867:

"Since the introduction of rifled artillery the size of powder grains has been enormously increased, with the intent of diminishing the strain visited upon the ordnance. The Americans have indeed gone to the extreme of abolishing grains altogether, or, if the expression be more allowable though seemingly paradoxical, they have manufactured each specific ordnance charge as one enormous grain."

Curtis and Harvey were already engaged in the manufacture of gunpowder in the form of highly compressed pellets. It had already invested in the plant. The magazine Engineering for 31st March 1871 reports:

"Observing the tendency of artillerists both at home and abroad to adopt pellet powder for heavy guns, Mr. Jabez James turned his attention to the production of a simple and safe press for the manufacture of the pellets. In 1869 he succeeded in perfecting an apparatus which he patented and which was at once adopted by Messrs. Curtis and Harvey at whose works at Hounslow there are now, and have been for the past two years, five of these machines working with perfect success."

There follows a description of the machines. These were essentially a hydraulic press operating on a large plate, perforated with holes of the size it was wished to make the pellets; each of the holes was fitted with an accurately machined ram to act on the column of inclosed gunpowder. A revealing fact given is that the pressure under which the powder for pellet propellant was compressed was 1,025 lb. (72 Kg/sq.cm.) (also that Russian powder of the same type made at the Okta factory was compressed at 2,150 lbs. per square inch (151 Kg/sq.cm.)). It might be supposed, therefore, that when the firm came to make E.S.M. powder similar high pressures were used. The only problem which might have been encountered here was that it is often difficult to apply great pressure uniformly throughout a column of particulate material

when that column is of any depth. E.S.M. powder may for this reason have been pressed in successive increments, so as to build up a length of solid cartridge gradually. Equally, it may be that cartridges were rather short: very long cartridges, no matter how well consolidated, must have been somewhat brittle. There is in fact no indication of just how long E.S.M. cartridges were. The term could as well have been used to describe cylinders of powder only a little longer than they were wide. The postulated adaptation of the pebble grain artillery powder machines may have been minimal.

Whatever became of very large grain ordnance powders, the firm of Curtis and Harvey had clearly over-extended its research and development department. There was no immediate order for the pebble powder. The article in Engineering for 3rd March 1871 (p.222), already cited, contains the following reproachful observation:

"The machine is worked by three men, and the pellets produced are clean made and hard, although up to the present time these pellets have not proved such a success as to lead to their introduction into the service, nor even to the duplication of the solitary mill at the Waltham mills..."

Five expensive machines were not to be allowed to lie idle from 1867 to 1871.

The Use of Black Gunpowder in Blasting

Discussion of the techniques which came to be used in the placing and firing of charges of black gunpowder will be deferred until a later chapter when the topic 'Bickford Fuse' will be considered. The reason for this deferment is simply one of economy. By carrying forward the discussion to a point in the work where the methods used can be described as general practices, applied without special regard to the particular explosive agent being used, it will be possible to avoid what

was foreseen as a tiresome repetition.

Blasting with gunpowder had been a commonplace long before the opening of the nineteenth century.* The scale of the work was usually small. Only in certain kinds of 'hasty military demolitions' were relatively large individual blasts initiated.** A civilian blasting operation of any magnitude was the exception, and attracted the notice of the press. The Practical Mechanic's Journal for 1st March 1870 devotes a paragraph to a description of a large blast. This is representative of many like accounts which appeared in the journals over the years:

"A large blast. - Recently at the extensive lime quarries of Messrs. Briggs, situated at Salthill, near Clitheroe, one of the largest blasting operations ever attempted in that part of the country was successfully brought to a conclusion. At Salthill there is a perpendicular face of mountain limestone sixty feet (18 m.) in height. A tunnel, twenty-eight yards (25.6 m.) in length, had been bored in the face, and sixty c.w.t. (3048 Kg.) of gunpowder well walled in at the upper end. Three fuses were lighted at 2.20 p.m., and at 2.54 p.m. a mass of at least 50,000 tons (50802 tonnes) of solid limestone was lifted perpendicularly a height of thirty or forty yards (27.5 m - 36.6 m.) So truly was the vertical movement affected that not a single stone was thrown a distance of more than eight yards, (65 m.) The huge mass went up together into the air, and, though crumbling in the descent, fell well together. Most of those present were scientific men, and afterwards dined together with Messrs. Briggs."

The relatively late date of this use of a large quantity of black gunpowder should be noted. The festive atmosphere of the occasion aside, the description in one of an efficiently managed blasting operation. A loud concussion and much flying debris is the mark of a wasteful blast. Three tons of explosive at a single firing is a large charge by any standard.

* One of the earliest recorded references to rock blasting with gunpowder in the United Kingdom is recorded in the Philosophical Transactions of the Royal Society, 1665-1666, pp.82-85. The paper is entitled: "A way to break easily and speedily the hardest rocks, communicated by the same person, as he received it from Monsieur du Son, the inventor."

** A detailed account of the use of gunpowder in all kinds of military engineering works can be found in Instructions to Military Engineers (Sect.23), 1870, School of Military Engineering, Chatham (By C.W. Pasley), 11th Edition, Horse Guards, London.

If the use of gunpowder declined it did so very gradually indeed. Oscar Guttman, writing as late as 1912, in his book, Twenty Years Progress in Explosives, (p.35) gives his own impression of the use of gunpowder:

"In common with others I once thought that the use of black gunpowder was dying out, and this perhaps will actually be the case one day; but I confess that I did not reckon sufficiently with the conservative inclination of the miner, who in many cases clings tenaciously to the old black powder ... blasting powder is still sold to such an extent that in the mines and quarries of this country alone nearly 7,000 tons (6,889 tonnes) of it, or more than half the total weight of all explosives, were used in 1907."

And, finally:

"There has been practically no progress made in black powder within the last twenty years."

Additional Note

Without doubt, the most comprehensive and detailed account of all the stages in the manufacture of good quality gunpowder is to be in the journal Engineering of 4th January; 18th January; 8th February; 22nd February; 15th March, and 29th March 1878, written by Mr. James A.C. Hay, Memb. Inst. M.E. and Assoc. Inst. C.E., & C. This series of articles could be said to describe gunpowder making at the virtual peak of its development. The date of the article is some three years later than the time chosen for the closing of this study, but for the very reason that it can be held to represent a summation of all technical development up to that point, it is cited. Where the article in Abraham Ree's Cyclopaedia offered what was essentially an eighteenth century view, J.A.C. Hay's work has a sharply modern, an almost twentieth century, flavour to it. Between the two there lies a little over fifty years.

CHAPTER 2

MERCURY FULMINATE

The inclusion of a consideration of the discovery of mercury fulminate, and of early attempts to make use of the discovery, requires some explanation, and some justification. The inclusion does indeed go beyond the declared bounds of this dissertation. But the digression will be strictly limited and will serve some useful purpose. The history of technology no more comes in discrete hundred year chunks than does political or social history, even though the firmly recorded date of this or that invention may sometimes give the impression that this is so. The choice was between crossing a declared boundary or leaving a striking hiatus. Along with black gunpowder, only the fulminates have any certain antiquity. Of all the explosive substances that were discovered during the nineteenth century, only mercury fulminate, among the useable explosives, had its discovery and the working out of safe and economical ways of preparing the compound before the period 1825 - 1875. The larger part of the source material for this study comes from this earlier time and had perforce to be followed where it led.

A necessary digression having been declared, its extent will be given point by point:

(a) Except for passing reference, only mercury fulminate will be treated because only mercury fulminate was to be used extensively in practice.

(b) The two principal uses for mercury fulminate were, in the first instance, as the active agent in percussion caps, and, in the second, as the initiator of other explosives. The development of the percussion cap is not seen as a part of the present study. Material which refers to percussion ignition will be introduced, but it will only be used so far as it helps something significant

to be said of the development of mercury fulminate.

(c) The question of primacy of invention or discovery is more than ordinarily vexed in the case of mercury fulminate. In this work the question will be only briefly rounded out; and this only so that the question can, for sufficient reason, be quickly put aside.

The Early History of the Fulminates

At first sight it may appear remarkable that mercury fulminate remained for so long a chance discovery, something stumbled upon from time to time by empirical chemists, working long before C.E. Howard published precise directions for its preparation. Kunckle^{*} is said to have obtained an impure specimen of it in 1700. The Dutch chemist, Cornelius Drebbel (1572 ~ 1633), has been cited as an even earlier discoverer.^{**} Certainly it was not for want of any of the three chemicals needed for its preparation that it was not discovered, nor was it that the available chemicals were not of a sufficient purity.

The reason for the apparent elusiveness lies not so much in the purity of the constituents as such. It is rather that the precipitation of a pure compound depends, critically, upon the proportions in which the constituents are brought together. It will be appropriate here to quote a relatively modern authority:

"... considerable supervision is necessary, as, unless the correct proportions of the ingredients are strictly adhered to, a very inferior product results, whilst as comparatively small variation in the proportions results in no fulminate being formed."

Modern Explosives, Colver, 1918.

* and ** A History of Chemistry by J.R. Partington, M.B.E. D.Sc. Vol.II., p.377 (and footnotes); Vol.III, p.257 (and footnotes), Pub. Macmillan 1964, London.

Much of the attention which had early attached itself to the fulminates was due to their spectacular property of detonation. That is to say the explosion was of extreme rapidity. This extreme rapidity of chemical reaction allowed the force of the explosion to follow the line of most resistance. Gunpowder followed the line of least resistance, which was why it had to be strongly confined to produce an explosion at all. No less an observer than Samuel Pepys* saw a demonstration of aurum fulmians in 1663, and noted particularly that a few grains of the substance heated in the bowl of a silver spoon struck downward when it went off. This was contrary to common experience and expectation.

But fulminating gold and silver could be no more than chemical curiosities. In addition to being expensive to make in any but minute quantities, they were also extremely sensitive and hence dangerous. The discovery of the fulminate of mercury by Howard meant that for the first time there was available a fulminating compound that was comparatively cheap to make, and could, therefore, be produced in some quantity. It was, moreover, quite stable and relatively insensitive. Detonation as a physical phenomenon was amenable to study.

It cannot be a part of the present work to attempt to trace the history of the fulminating substances further. The references to them found in the literature so far have been seductively fascinating. But they stretch backwards in time, contrary to the direction in which this study is aimed. Consequently, and in order to rule a firm line under the above statement, a chance come-across but singularly apt quotation which points up the nature of the problems which have been encountered in previous attempts to determine firm origins for the fulminates is

*(Quoted in Explosives by J. Read, Penguin, 1942).
Samuel Pepys Diaries: 11th November 1663.

taken from J. Beckman's History of Inventions and Discoveries, translated by Johnston, (Volume I), Bohn's Scientific Library, London, 1846.

The extract concerns fulminating gold, but it applies equally well to the other fulminates:

"He who attempts to trace out the invention of aurum fulmians is like a person bewildered in a morass, in danger every moment of being lost. I allude here to the immense wilderness of the ancient alchemists..."

The Discoverer of Mercury Fulminate

The identity of the 're-discoverer' of mercury fulminate in early modern times was, and probably still is, in passive dispute. The principal candidate, after Howard, is the Frenchman, Pierre Bayen, who was chief military physician to Louis XIV. Howard himself was well aware of the claims made for Bayen and countered them in scholarly fashion, citing French published papers, in the course of his own paper on his discovery.

In the briefest of terms, Howard was of the opinion that what Bayen had discovered was a mixture of the nitrate of mercury and sulphur, and no true fulminate.

At this point, in this dissertation, the question is left on the table. The available information, such as it is, is given. Since only English sources are readily available, it would not be proper here to make any assertions. For the purposes of this study it will be assumed that Howard isolated the pure compound, $\text{Hg C}_2 \text{N}_2 \text{O}_2$, in 1799.

However, and just to kite a rag of the area of possible dispute, a reference from a currently in-print (1980) French work, written at the semi-popular level, is here quoted:

"Le fulminate de mercure avait été découvert, en 1775, par Bayen. Howard trouva le moyen de l'utiliser comme amorce en la mélange du salpêtre."

("Mercury fulminate had been discovered, in 1775, by Bayen. Howard found the method of using it as a priming substance, in a mixture with saltpetre.")"

L'Expansion De Machine
by Daumas (p.464), Presses Universitaires
De France: 1968.

The above represents historical truth at the 'received' level for French speaking peoples. It represents the establishment of 'fact' by the accretion of opinion. French sources will tend to support one proposition, English a contrary one. After some time - as source builds upon source - the positions become polarised along nationalist lines. The fact of the matter may lie somewhere along a cline embodied in the relative proportion of mercury fulminate, proper, of nitrate of mercury, or of free metallic mercury, precipitating out at the bottom of a chemist's flask.

The discovery that the Honourable Charles Edward Howard made, then, was not so much the discovery of mercury fulminate. That had, it seems likely, been done centuries before. It is rather than Howard chanced upon certain proportions of the three constituents which gave a sample of the compound sufficiently pure for its extraordinary properties to demonstrate themselves.

The Date of Howard's Discovery

The date of Howard's discovery has been represented variously as 1799 and 1800. No closer date has been found during the present study. Howard's paper, "On a New Fulminating Mercury," was published in the Philosophical Magazine for June of 1800, having beforehand been read on the 13th of March 1800 to the Royal Society. However, the edition of the Philosophical Magazine for June 1799 advertises Howard's discovery:

"We have now to announce, that a method of preparing an oxyd of mercury, different from any described by Bayen or others ... has just been discovered by Mr. Howard. We have not yet received a correct account of the process for preparing it..."

It is possible to speculate here. The earliest date for the discovery would seem to be some time, more or less, before the middle of 1799. And this much at least establishes the date to the year. But was it sooner than June 1799, or later? Particularly, did Howard make his discovery well before June of 1799? Did he then have his serious accident with the compound?

"I once poured six drams (15 gms) of concentrate acid upon fifty grains of powder. An explosion, nearly at the instant of contact, was effected: I was wounded severely, and most of my apparatus destroyed..."

Did this incapacitate him until some little time before June 1799, when he was well enough to communicate the fact - but not the process - of his discovery to the editor of the Philosophical Magazine? It could on the other hand be asked if it were not more likely that Howard communicated his findings in outline, intending to elaborate more fully when he had completed his experiments, then, during the course of his experiments, he blew himself up. This would account for the year-long delay between the advertisement of the discovery and its presentation in a paper. If, in the above given quotation, the words, 'has just been

discovered', have any significance, the latter alternative would seem to be the most likely: C.E. Howard discovered his mercury fulminate some little time before June 1779.

Howard's Researches into the Properties of Mercury Fulminate

Having isolated the new compound, Howard set out to examine its properties fully in an extended series of experiments. The essentials of his findings are here given. The headings refer to the section of Howard's article in the Philosophical Magazine from which they were taken.*

Section I. The fulminate was susceptible to detonation by simple percussion.

Section II. The fulminate could be detonated by electric shock.

Section III. The fulminate exploded at a temperature of 368 degrees Fahrenheit (187°C).

Section IV. The fulminate did not produce any great recoil when exploded in a powder-proof, but that in the same test it shattered the barrel of the proof very completely.

Section V. The fulminate was found to be actually inferior to common gunpowder when it was attempted to use it as a propelling charge - but that, as with the powder-proof, the barrel of the gun was 'burst in an extraordinary manner'.

Section VI. That the fulminate, again compared with common gunpowder, as a bursting charge, displayed a severely shattering effect : '... the mercurial powder appeared to have acted with great energy, but only within certain limits'.

(The experiment which came under the heading 'Section VII' of Howard's article allowed no certain conclusions. He had attempted to compare the yield of gas from mercury fulminate with that from black

*The Philosophical Magazine and Journal, 10th July 1800, Vol.VII.

powder by exploding small quantities of each within a closed glass sphere, and noting the amount of displacement when the gases resulting from the explosions were led under a glass jar in which there was a head of mercury. The experiment was inconclusive because, as Howard saw, the gases deriving from the conflagration of the gunpowder were partly reabsorbed by the powder residues.

But the means Howard employed at this early date warrant special mention:

"I placed ten grains (6.48 grams) of the mercurial powder on very thin paper, laid an iron wire 149th of an inch (0.17 mm) thick across the paper, through the midst of the powder, and, closing the paper, tied it fast at both extremities with silk, to the wire ... Such a charge of an electrical battery was then sent along the wire ... making the wire red hot ..."

In his experiments on mercury fulminate E.C. Howard would appear to have used what was, in all its essentials, an electrical means of ignition).

Section VIII. That the brissance displayed by the mercury fulminate could not be attributed to the mere volume of the gases generated; nor, entirely, to the speed of the reaction.

(Howard, it is suspected, was trying to express his insight in the terms of a nomenclature that was not quite adequate to the concepts he wished to express. This is not at all surprising; there was likely to have been little in either his previous reading or his previous experience upon which he might base his exposition. He writes, to cite a single example, of 'the rapidity of its combustion', and not of detonation).

The following short quotations will give the essentials of the ideas Howard wished to express in Section VIII.

(a) "... it is not to be supposed that the generation, however, rapid, of four cubical inches of air will alone account for the described force..."

(b) "The sudden vapourisation of a part of the mercury seems to me the principal cause of the immense, yet limited, force; because its limitations may then be explained, as it is well known that mercury easily parts with caloric and requires a temperature of 600 degrees Fahrenheit (316°C) to be maintained in the vapour state."

(c) "That mercury is really converted into vapour, by ignition of the powder, may be inferred from the thin coat of divided quicksilver, which, after the explosion in the glass globe, covered its interior surface..."

Section IX

Howard devotes Section IX of his publication to describing in detail his process for producing mercury fulminate. Again, his description shows meticulous observation; so much so that it promotes an inclination to believe that later researches tend toward the merely replicative. Later refinements took advantage of advances in chemical theory and in techniques for accurate analysis; real but rather pedestrian advances lay in the management of bulk production and handling.

The section is here quoted almost in its entirety with Howard's own footnotes inserted into the main text, within brackets. The passage is given in its entirety because it is felt that it will show that when the process described by Howard is compared with those dating from as much as forty years later it will be allowed that C.E. Howard had arrived quickly at a process of manufacture that was virtually complete.

"... 100 grains (6.5 grams), of a greater proportional quantity, of quicksilver, not exceeding 500 grains (32.4 grams), (the reason of the limitation is not on account of any danger attending the process but because the quantities of alcohol required for more than 500 grains would excite a degree of heat detrimental to the preparation), are to be dissolved, with heat, in a measured ounce and a half of nitric acid (of specific gravity of about 1.3). This solution, being poured cold upon two measured ounces of alcohol (of specific gravity of about .849), previously introduced into any convenient glass vessel, a moderate heat is to be applied until an effervescence is excited.

A white fume then begins to undulate on the surface of the liquor; and the powder will be gradually precipitated, upon the cessation of the action and reaction.

The precipitate is to be immediately collected on a filter, well washed with distilled water, and carefully dried in a heat not much exceeding that of a water bath. The immediate edulcoration of the powder is material, because it is liable to the reaction of the acid; and whilst any of that acid adheres to it, it is very subject to the influence of light.

Let it also be cautiously remembered, that the mercurial solution is to be poured upon the alcohol.

I have recommended quicksilver to be used in preference to an oxyd, because it seems to answer equally, and is less expensive; otherwise, not only the pure oxyd, and turpeth may be substituted; neither does it seem essential to attend to the precise specific gravity of the acid or the alcohol. The rectified spirit of wine and the nitrous acid of commerce never failed, with me, to produce a fulminating mercury. It is indeed true, that the powder prepared without attention is produced in different quantities, varies in colour, and probably in strength. From analogy, I am disposed to think the whitest is the strongest; for it is well known, that black precipitates of mercury approach nearest to the metallic state. The variation in the quantity is remarkable; the smallest quantity I ever obtained from 100 grains (6.48 grams) of quicksilver being 120 grains (7.8 grams), and the largest 132 grains (8.6 grams). Much depends on very minute circumstances. The greatest product seems to be obtained when a vessel is used which condenses and causes most ether to return into the mother liquor; besides which, care is to be had, in applying the requisite heat, that a speedy and not a violent action be effected. 100 grains (6.5 grams) of an oxyd are not so productive as 100 grains of quicksilver.

As to the colour, it seems to incline to black, when the action of the acid on the alcohol is most violent, and vice versa."

Howard's Discovery as an Example of 'Serendipity'

Since in his paper Howard declares that he was attempting to show that hydrogen was the basis of muriatic acid (Hydrochloric acid), the discovery of mercury fulminate must rank as a first rate example of Serendipity: the finding of something of value while making a futile search for something quite different.

It might also be said that the discovery, and more to the point, the securing of the discovery, depended as much upon anything else upon the availability of accurate measures and balances; and upon the practice of making an accurate record of what was done. Had Howard been killed during the course of his researches - as he so nearly was - it is reasonable to conjecture that the elusive compound could have slipped back into obscurity. Though, again, it is suspected that with the great expansion of chemical research that began early in the nineteenth century it would not have long remained so. The historical records concerning the fulminates generally were available. It is observed that C.W. Scheele used the example of fulminating gold to support his arguments in support of the Phlogiston Theory. Because the fulminates represented an obvious and to begin with, an only lead in any search for substances with explosive properties, it is also reasonable to suggest that the group of compounds would have come in for some attention. Systematic work on any of the few possible combinations which lead to the formation of a metallic fulminate would, it is felt, have before very long have led to an independent discovery, somewhere.

The Trials at Woolwich

Howard, as has already been stated, announced his discovery to the Royal Society on the 13th March 1800. Before June of the same year, Lord Howe, Lieutenant General of the Ordnance, had given leave for trials to take place at Woolwich. It should be said that the term 'trials' is used loosely - the experiments which Howard supervised seem to have been informal and very limited.

The tests carried out were to explore the fulminate's explosive potential. Howard himself may have suggested the form they were to take because he had already worked out the broad outlines of the fulminate's properties. In the round, it could be said that the experiments aimed at comparing mercury fulminate with common gunpowder as a propelling charge and as a bursting charge.

Seven experiments were carried out. The limited nature of the tests is indicated by the information that the total weight of fulminate available - as totalled up from Howard's account in his paper - seems to have been no more than twenty ounces (Troy weight), that is, only 622 grams of explosive.

In Experiment One, $3\frac{1}{4}$ oz. (Troy), (101 grams) was exploded in a cast iron case which was in turn, in order to prevent the splinters from flying, fitted into the bore of a twelve pounder carronade. The carronade was undamaged. Half of the case, however, was flung from the muzzle of the gun. And the half which remained:

'was cracked in every direction, and in part crumbled; yet it was so wedged into some indentations which the explosions had made in the sides of the piece that the fragments were not removed without great labour.'

This must have been something entirely new even to these experienced ordnance officers: the fusing, or near fusing, of one metal to another by

sheer explosive impact (it comes to mind that the shaping of metals by explosion in a way related to the above is a very modern industrial process).

The arrangement of Experiment Two was similar to that of Experiment One, except that the charge of fulminate was of five ounces (Troy), (158 grams) and the carronade was triple shotted. The result was similar to the above except that the shot, cast iron roundshot, were cracked to pieces.

It is suggested that the roundshot were cracked and crumbled because they offered to the exploding fulminate a line of most resistance, and as a consequence it was these that took the main force of the detonation. Once again fragments were impacted fast to the metal of the carronade's bore - so much so that Howard reports that the vent had to be re-drilled before the next test could take place.

Experiment Three was a test of the fulminate's potential as a propellant. The carronade was charged with fully five ounces (Troy) (156 grams) of mercury fulminate. With the piece wadded and loaded to the muzzle with shot, it was fired off at a block of wood, 'set at some small distance, to receive the impression of the shot'. There was a louder noise from the discharge than they had previously noted, the recoil also was greater. But as a propellant, clearly they would have been hoping for a powerful alternative to gunpowder, the fulminate was a disappointment. The target block of wood was 'not penetrated by the shot above the depth of one inch'.

In Experiment Four, there remained insufficient fulminate to hand for a full charge for the twelve pounder carronade, so a half-pounder swivel-gun was used. This gun was charged with an ounce and a half (Troy)(47.26 grams) of the fulminate. It was then loaded with a single shot of one and a half pounds weight (0.6 Kg.), set between two wads. If the new explosive made a poor propellant it wanted nothing as a means

of shattering ordnance:

"The piece was destroyed from the trunnions to the breech, and its fragments thrown thirty or forty yards (27 m - 36 m.) ... the part of the swivel not broken, was scarce, if at all, moved from its original position."

The violence of the fulminate in bursting a gun barrel may well have determined the form of experiments, five, six, and seven, for these were, respectively, upon the effects of mercury fulminate bursting charges enclosed within a 4.4 inch (11 cm.) shell, a 'sea-service' grenade case of 3.5 inches diameter (9 cm.), and another case of the same size, but charged with a smaller quantity of fulminate.

In all cases the ordnance officers were likely to have been disappointed yet again. All the cases were very thoroughly shattered, but none of the explosions threw the fragments for any distance or with any force. Obviously this last would be a first requirement in a bursting charge.

Mercury fulminate may have had a use, as Howard had first suggested, in the blowing up of enemy guns. But it is unlikely to have escaped the notice of the ordnance officers that a man carrying a parcel of fulminate during an action would be a greater danger to his own side than to enemy guns.

The relative failure of the experiments at Woolwich may have served to reduce at least any official interest in mercury fulminate. If the material dealing with it is as sparse as it seems to be, then it might be said that after the Woolwich experiments mercury fulminate was relegated to being a chemical curiosity. In 1800 Britain was in the middle of a series of long wars with the French and their allies. It is certain that any discovery which offered a hope of technical advantage would have been seized upon quickly. However, for want of an application, the trials showed mercury fulminate to have no properties which might recommend it as a possible substitute for black gunpowder.

There is no explicit mention of any such attempt, but it would seem reasonable to suppose that it would occur to someone to mix the fulminate with common gunpowder in the hope of enhancing its power. This would only be the taking up of one of a very few options open to the experimenters. Mr. Cruikshank, one of the officers present at Woolwich, may have had this in mind. Howard states:

"Mr. Cruikshank, who made some of the powder by my process, remarked that it would not inflame gunpowder. In consequence of which, we spread a mixture of coarse and fine-grained gunpowder upon a parcel of the mercurial powder; and, after the inflammation of the latter, we collected most, if not all, of the grains of gunpowder. Can this extraordinary fact be explained by the rapidity of combustion of fulminating mercury? Or is it to be supposed, (as gunpowder will not explode at the temperature at which mercury is thrown into vapour), that sufficient caloric is not extricated during this combustion?"

The speed and violence with which mercury fulminate reacted, the quality which was to make it so very important later in the century, made it relatively unuseable in 1800. Such situations are not uncommon in the history of technology - the attendant circumstances of a discovery are also vitally important. Howard conceded at the end of his paper:

"But the great danger attending the use of fulminating mercury, on account of the facility with which it explodes, will probably prevent its being used for that purpose."

Nevertheless, it can be said that one thing came out of the trials which was of importance to the history of technology. It seems almost certain that the explosive phenomena observed by Howard and his colleagues was something quite beyond their experience. The seven experiments which were carried out at Woolwich in June of 1800 may be regarded as a first opportunity - anywhere at all - to observe the effects of a true high explosive on a scale greater than that undertaken in the laboratory.

The Introduction of Percussion Firing (1800 - 1839)

Following the Woolwich experiments and the failure of the commission of Ordnance Officers to find an application for it, mercury fulminate seems to have received little official attention for a quarter of a century and more afterwards. The first extensive application for mercury fulminate came with the invention of percussion ignition firearms by the Reverend Alexander Forsyth in 1805 and their later improvement by E.G.Wright.

The advent of percussion firearms prepared the way for the breech-loading firearms which were one of the many factors which allowed the expansion of the European powers into their direct colonial phase. But while the use of mercury fulminate aided the development of the percussion weapons - it was reliable in its action - it was not essential to either the percussion cap, nor indeed to the self-contained cartridge which quickly replaced the cap. A clear example of this is the Dreyse Needle Gun. This breechloading rifle was invented in 1844 and was in service with the Prussian Armies for many years. The Dreyse cartridge was primed with a mixture containing chlorate of potassium, sulphur, antimony sulphide, and glass powder. No mercury fulminate was used. The Dreyse rifle is generally held to have been decisive in the Franco-Prussian War of 1870.

English practice, however, perhaps because it was chiefly concerned with sporting guns, preferred compositions containing mercury fulminate. This may have influenced the choice of mercury fulminate as the principal constituent of the caps adopted for the British Army after 1832. The chlorate mixtures used on the Continent had known drawbacks in use.

As late as 1832 a correspondent to the Philosophical Magazine & Journal* complains of the tendency for chlorate priming to promote rust

*XII. On the Firing of Gunpowder by Fulminating Mercury by Mr. E.G.Wright, Philosophical Magazine & Journal, 30th September 1832.

and fouling at the nipples of sporting guns. He gives detailed instructions - a recipe virtually - for the making of mercury fulminate at home.

"My method of preparing mercury fulminate is as follows:- I place two dracms (9.33 gram) of quicksilver in a Florence flask, and pour six dracms (measure) of pure nitric acid on the mercury; this I place in a stand over a spirit lamp, and make it boil, till the quicksilver is taken up by the acid; when nearly cool, I pour it on an ounce measure of alcohol in other flask: sometimes immediate effervescence ensues, with the extrication of nitrous ether; and I have often been obliged to place the mixture over a lamp, till a white fume begins to rise, when the effervescence follows. I suffer the process to continue (removing the lamp) till the fumes assume a reddish hue: when I pour water into the flask, and the powder is found precipitated to the bottom, I pour off and add fresh water, permitting the powder to subside each time before the water is poured off, so as to free the substance as much as possible from the acid; and then I pour it on a piece of filtering paper, and place the powder in an airy room to dry..."

The nomenclature the correspondent uses is archaic to the modern reader, but Mr. Wright gives every impression that, in an empirical fashion, he knew what he was about.

"Sometimes the powder is quite white, and often light brown; but this is of no consequence..."

Although the undertaking in the round is hazardous, Mr. Wright is aware of the dangers:

(a) "It should be kept in a corked (not stoppered) bottle..."

(b) "The fulminating mercury ought to be made in an out-house, or in an unfurnished room, under a chimney, on account of the nitrous fumes extricated in the first, and the nitrous ether in the second part of the process..."

(c) "To fill the caps, I use a small ivory pin scooped out at one end."

Since one kilogram of fulminate was sufficient to prime 59,000 sporting percussion caps (40,000 military musket caps), it is possible to make a close estimate of Mr. Wright's scale of production.

Two 'dracms' (sic drachms) of mercury metal weigh .25 of one ounce

in Apothecary's measure, which was derived from Troy weight. If an increase in weight of 20 per cent is assumed to result from conversion into the fulminate, the final yields would be .3 of one ounce. Since one ounce was equal to 480 grains in Apothecary's measure, .3 of one ounce was equal to 144 grains. Now, one gram, metric system, is equal to 15.432349 grains (Miller 1856); consequently, 144 divided by 15.432349 gives 9.33 grams. If 1000 grams is sufficient fulminate to make 59,000 caps, 1 gram will make 59 caps; 9.33 multiplied by 59 gives 550. Mr. Wright was making - somewhere in the region of - five hundred and fifty percussion caps at home.

The above estimation is probably somewhat on the high side since the quotation of output is taken from an observation of government establishment where, presumably, the workmen would be more skilled.

Wright's process shows virtually no advance on that described by Howard thirty-two years before. The process is simple, the apparatus is simple and it is designed for a very limited scale of production. Again, since there was no application for the fulminate except as a filling for percussion caps for sporting guns, there looks to have been no development in the techniques for its production.

"RESEARCHES ON FULMINATING MERCURY"
(Andrew Ure's Report to the Board of Ordnance)(1831 - 1832)

The first general application of mercury fulminate to a national purpose in the United Kingdom came with the decision to adopt a percussion lock musket for the use of the armed forces in 1832. This represented a major advance in military technology in so far as the intention was to replace the flintlock musket entirely; thereafter, musket would mean percussion musket, and all that might mean to the way in which war was conducted. But for present purposes the important implication of the changeover was that mercury fulminate entered into a widespread use.

For the first time there was a demand for it in quantity. That demand was only to be met if properly controlled processes were worked out for all the stages of its manufacture, handling, and storage.

Dr. Andrew Ure's report^{*} on the experiments he carried out on mercury fulminate during 1831 at the direct behest of the Board of Ordnance shows the state of the technology available for manufacturing the fulminate at the time. It shows that even some thirty years after Howard's original researches the preparation of mercury fulminate was by no means a certain process.

The reason for so searching an enquiry is not difficult to understand. The Board of Ordnance would be greatly concerned to be assured that the quality and the supply of mercury fulminate would be reliable in every way. Some centuries of experience lay behind the flintlock. The adoption of the percussion system meant the replacement of the fine powder priming, which was the same in kind as the main charge, in the flintlock, by a device which depended entirely upon a few crystals of a metallic salt held in a matrix with shellac. Service conditions, above all, require reliability and robustness. The Board would have had to have been thoroughly convinced that mercury fulminate could be produced without any faltering in any part of the process. The fulminate would have been seen as the most essential part of the system; also as the least reliable, if the capricious and violent nature of its action when exploded in any bulk were an indication. The stable behaviour of percussion caps in bulk must have been suspect - paradoxical - until Dr. Ure had carried out the most extensive tests.

^{*} A Dictionary of Manufactures and Mines (Containing a clear exposition of their principles and practice) by Andrew Ure, M.D. (p.531), Pub. Longman, Orme, Brown, Green, Longmans, London, 1839.

In his original report, Ure was required to give answers to a number of quite specific questions. No information has been found which indicates the composition of that particular board of enquiry, but it seems clear that the members already knew something of mercury fulminate, and they knew which questions would have to be answered in the most unequivocal way. In order to answer the Board's questions, Ure undertook what he termed, 'a numerous, diversified, and somewhat hazardous series of experiments'.

In his introduction, Ure clears the ground when he states expressly:

"The only kind (of fulminate) at all interesting in a manufacturing point of view, is the fulminate of mercury, now so extensively used as a priming to the caps of percussion locks."

The first of the Board's questions is significant in that it shows that there was no ready and accepted answer to it available at the time.

"Question 1. What proportions of mercury, with nitric acid and alcohol of certain strengths, will yield the greatest quantity of pure mercury fulminate?"

The answer is given in two forms: in the first it is given in the chemical nomenclature of the time; in the second it is an answer for practical men.

"Hence, in round numbers, one ounce weight of quicksilver must be dissolved in $7\frac{1}{2}$ oz. of the above designated nitric acid, and the resulting solution must be poured into 10 oz. measure of the said alcohol."

The second of the Board's questions is really several questions compounded:

"Question 2. What is the most economical and safe process for conducting the manipulation, either as regards the loss of nitrous gas and residuum, or as respects danger to the operator; also, what is the readiest and safest mode of mixing the fulminate intimately with its due proportions of common gunpowder?"

Ure's answer to the second question is very full in respect of all parts save that which concerns the danger to the operator. There is no reference - even indirectly - to the possibility of accidental explosion during manufacture. The article is claimed to be a verbatim copy of the report.

It may be that the Board of Ordnance may have been concerned with more than just the purely service aspects of the innovation. The cost of introducing the percussion system would have had to have been worked out carefully. The financing of a process in which there was some uncertainty about the most economical proportions of expensive constituents to use, about the return of fulminate to be expected, and one moreover where it looked as though a large part of those expensive constituents were for practical purposes lost during the course of the reaction, would, it is certain, have called for the closest of enquiries. And where Andrew Ure does answer the Board's questions he does so in the fullest fashion. The main body of his report, where it is concerned with mercury fulminate, will stand quite extensive quotation for the detail it affords.

"The mercury should be dissolved in the acid in a glass retort, the beak of which is loosely inserted into a large balloon or glass or earthenware, whereby the offensive fumes of the nitrous gas disengaged during the solution, are, in considerable measure, condensed into liquid acid, which should be returned into the retort. As soon as the mercury is all dissolved, and the solution has acquired the prescribed temperature of about 130° (54°C), it should be slowly poured, through a glass or porcelain funnel, into the alcohol contained in a glass matrass or bottle capable of holding fully six times the bulk of mixed liquids. In a few minutes bubbles of gas will proceed from the bottom of the liquid; these will increase in number and magnitude till a general fermentative commotion of a very active kind is generated, and the mixture assumes a somewhat frothy appearance, A white voluminous gas now issues from the orifice of the matrass, which is very

combustible and must be suffered to escape freely into the air, at a distance from any flame. These fumes consist of an etherous gas, holding mercury in suspension or combination. I have made many experiments with the view of condensing this gas, or at least, the mercury, but with manifest disadvantage to the perfection of the process of producing the fulminate. When the said gas is transmitted through a glass tube, into a watery solution of carbonate of soda, a little oxide of mercury is, no doubt, recovered; but the pressure on the fermentative mixture, though slight, necessary to the displacement of the soda solution, seems to obstruct or impair the generation of the fulminate; this effect is chiefly injurious towards the end of the operation when the gaseous fumes are strongly impregnated with the nitrous gas. When this is not allowed freely to come off, a portion of the subnitrate or nitrate of mercury is apt to be formed, the injury of the general process and the product.

As soon as the effervescence and the concomitant emission of gas are observed to cease, the matrass should be turned out upon a paper double filter, fitted into a glass or porcelain funnel, and washed by the affusion of cold water till the drainings no longer redden litmus paper. The powder adhering to the matrass should be washed out and then thrown onto the filter with the help of a little water. Whenever the filter is thoroughly drained, it is to be lifted out of the funnel and opened out on plated copper or stoneware, heated to 212° Fahr. by steam or hot water. The fulminate being thus dried, is to be put up in paper parcels of about 100 grains (6.5 grams) each; the whole of which may be afterwards packed away in a tight box, or a bottle with a cork stopper. The excellence of the fulminate may be ascertained by the following characters. It consists of brownish grey small crystals which sparkle in the sun, are transparent when applied to a slip of glass with a drop of water, and viewed by transmitted light. These minute spangles are entirely soluble in 130 times their weight of boiling water; that is to say, an imperial pint will dissolve 67 grs. (4.3 grams) of pure fulminate. Whatever remains indicates impurity. From that solution beautiful pearly spangles of fulminate fall down as the liquid cools."

Since the means of preparing a very pure fulminate were to hand, and was not used, it may be reasonable to assume that the presence of a small amount of impurity was not considered to be a disadvantage; that mercury fulminate was found to be at least chemically stable. The additional stage of refinement by recrystallisation could hardly have added greatly to the cost:

"It may now be proper to show within what nice and narrow limits the best proportions of the ingredients used in making the fulminate of mercury lie. The following are selected from among many experiments instituted to determine that point, as well as the most economical process."

"1. According to the formula given by the celebrated chemist, Berzelius, in the fourth volume of his Traite' de Chimie recently published (p.383), the mercury should be dissolved in twelve times its weight of nitric acid sp. gr. 1.375; and alcohol of sp.gr. 0.850, amounting to 16.3 times the weight of mercury, should be poured at intervals into the nitric solution. The mixture is then heated till effervescence of the characteristic cloud of gas appears. On the action becoming violent, alcohol is to be poured in from time to time till an additional 16.3 parts have been employed.

On this process I may remark, that it is expensive, troublesome, dangerous and unproductive of pure fulminate. One fifth more nitric acid is expended very nearly than what is necessary and almost four times the weight of alcohol at 0.83 parts by weight are sufficient; whereas Berzelius prescribes nearly four times the quantity in weight, though this alcohol is somewhat weaker, being of sp. gr. 0.085. By using such an excess of alcohol, much of the fulminate is apt to be revived into globules of mercury... at the end of the process ... 100 parts of mercury treated in the way recommended by Berzelius afforded me only 112 parts of mercury fulminate instead of the 130 obtained by my much more economical and safe proportions and process from the same weight of quicksilver.

(If it is suspected from Ure's forthrightness of diction in his writing style that he was being partisan or was canvassing his own process, it should be said by way of balance that a certain literary irascibility

marks a lot of his writing, even when the subject matter could not be thought other than neutral. It should also be said that Ure's articles give every impression of an exceptional thoroughness).

Dr. Ure goes on to describe for the Board of Ordnance a series of experiments in which he sets out, first of all, to determine the quantity of fulminate which results from varying the relative proportions of the constituent chemicals used in making the fulminate, and, secondly, to show the effect of making changes in the increment of alcohol added to the dissolved mercury. The work is clearly an attempt to find a best method, an optimum process, and at giving a number of rule-of-thumb observations to help the working chemist:

(a) "... the product of such proportions will either be not granular and therefore not fulminating, or it will be partially granular and partially pulverent, being a mixture of fulminate and sub-nitrate of mercury ill-adapted for priming..."

(b) "In fact, whenever the etherous fermentation is defective, or not vigorous, little true fulminate is generated; but much of the mercury remains in the acidulated alcoholic liquid..."

(c) "If the alcohol be poured in successive portions, and of proper strength (sp.gr. 9.83) into a proper nitric solution of mercury, the explosive action which accompanies each effusion dissipates much of the alcohol and probably impairs the acid so that the subsequent etherous fermentation is defective, and little good fulminate is formed ..."

(d) "... if the matrass be immersed in cold water so as materially to repress that action, the process will be impaired, and will turn out ultimately defective both as to the quantity and the quality of the fulminate. It is, therefore, certain that a certain energy or vivacity is essential to the full success of this curious process, and that anything which checks or obstructs its taking place is injurious and to be avoided..."

(e) "When other proportions (proportions other than those advocated by Ure himself) are taken, much more acid remains. This acid is not recoverable to any useful or economical purpose, nor is the alcohol that is associated with it..."

(f) "I have stated that my maximum product of fulminate from one hundred grains of quicksilver is 130 grains..."

Dr. Ure's paper makes no mention of the scale of manufacture. However, a little reflection supported by a very little arithmetic will show that in real terms the scale of production needed to meet the new demand for fulminate could be described as extremely modest. Whatever buildings and machinery may have been required for making the cases for the percussion caps, the apparatus necessary for making the mercury fulminate itself would, it is calculated, have needed to have been surprisingly small.

Consider:

(a) It is reliably recorded* that one kilogram of the fulminate sufficed to prime 40,000 of the large military pattern percussion caps.

(b) Assume the need to supply one million men with percussion caps. This is almost certainly an over-large estimate. Even if the needs of the standing army, the forces of The Honourable East India Company, all other Colonial forces and constabularies, allies and client princes, are included, it seems unlikely that there was a full million men under arms in the whole of the British Empire in 1832.

(c) Allow that an annual expenditure of fifty rounds of ball cartridge per man is prodigal - twenty rounds is thought to have been more usual.

Then, even on these deliberately gross estimates, it might be said that:

$$1,000,000 \times 50 = 50,000,000 \text{ percussion caps;}$$

$\frac{50,000,000}{40,000}$	percussion caps per kilogram of fulminate	= 1250 kilograms of mercury fulminate to be made per year
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And, $\frac{1250 \text{ kilograms}}{50 \text{ working weeks}}$ per year	= Approximately 25 kilograms of fulminate to be made per week. Or, just over 4 kilograms of fulminate per day during a six day working week.
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* Wagner, p.153.

Now, since one kilogram was equivalent to 2.2046 Imperial pounds, four kilograms, a day's through-put, would be equivalent to 8.8184 pounds, or to 564.4 quarter ounces. If we assume that the unit or batch size of manufacture was only the same size as that described previously by E.G. Wright, then, allowing a notional twelve charges per matress per day, only forty-eight flasks would have been required.

In practice, it seems reasonable to suppose, larger quantities of fulminate were made at one time. But even so, the flasks could have been many times the capacity of those used by Wright and still not have taken up very much more room. If the flasks used were approximately spherical in shape, their capacity would vary as the cube: a doubling of the dimensions would lead to an eightfold increase in volume. A quite large increase in the size of vessel used - and hence in the amount of mercury entering into a reaction - would not greatly increase the space needed for the apparatus.

The remainder of Dr. Ure's report deals with the destructive testing of packets of musket caps. That work cannot concern the present study directly, but it must be remarked that the adoption of the percussion lock using mercury fulminate caps was not done without the most extensive and rigorous testing being done beforehand.

It was suggested earlier that from the first discovery of mercury fulminate there might have been an expectation or a hope that it would allow some enhancement of the power of gunpowder. In the first instance, in the Woolwich tests, this seems not to have been found possible. Any admixture of gunpowder and mercury fulminate which might be used for blasting would almost certainly have been prohibitively expensive, and dangerously sensitive. But that was for an over all increase in the range of possible energy release. It was, however, realised by the time that mercury fulminate came to be used for percussion caps that the cap increased

the impetus of the musket ball:

"Mr. Lovell, of the Royal Manufactory of Arms has lately executed a series of experiments ... for the purpose of ascertaining what is the advantage in point of force obtained by using percussion primes. He had anticipated some extra energy would be imparted... he attributed most to the quickness and energy with which the powder charge is ignited by the vivid stream of flame generated by the percussion prime."

Upon reading Ure's account of Mr. Lovell's experiments, it is difficult not to arrive at the opinion that the leap between the percussion cap and the blasting cap was a very short one, and one in which the direction was perfectly clear. The copper cap was enlarged and extended; the 'spit' at the end of a length of burning Bickford fuse was substituted for the striking of the hammer; the nature of the charge was different. To the modern observer this seems to have been a rather major advance, which for some reason was not made when it might have been.

As a source document, Ure's report affords a striking illustration of the translation of chemical theory and laboratory practice into working industrial production. It is of a general interest because it comes from a time which might be considered to lie somewhere within the blurred edge of the transition between late empirical and early scientific chemistry.

Mercury Fulminate in Terrorist's Grenades

There was at least one practical application for mercury fulminate which attracted public attention - the political terrorist's bomb. The Illustrated London News of 27th February 1858 shows an engraving of a bomb casing:

(a) "This terrible instrument of destruction is hollow, of polished steel ... a cylinder about ten inches long (25.4 cm.) and six inches in diameter (15 cm.), terminated by two spherical ends. One of the ends is provided with twenty-five ordinary gun nipples, screwed in and furnished with caps ... the upper part being much thinner, in order that the superior weight of the former may strike first upon the ground and explode the machine..."

(b) "It was charged with a pale yellow, fine, crystalline, heavy substance, which it has been ascertained to be pure mercury fulminate... the experts several times let the shell fall on the ground ... at the height of a man's waist, and in every instance some caps exploded the moment it fell."

What is remarkable about this instance is that for the rather limited - limiting - profile of properties which mercury fulminate offered, a precise use was found on at least this one occasion. As a filling for a terrorist's bomb, mercury fulminate was a sound choice: it was, as was tested, very likely to have been reliable in use; the extreme brissance of the fulminate would have produced, within a relatively limited radius, the most gruesome of rending effects; and cost, when it is considered that the intended victim was Napoleon III, would not have been prohibitive.

Mercury Fulminate as an Industrial Hazard

Some idea of the scale of production, and incidentally of the laissez-faire conditions under which small entrepreneurs were allowed to work with sensitive explosives in urban areas, can be gained from a close reading of an account of an explosion which occurred at Birmingham in 1862.

"Birmingham was the scene of a terrible explosion on Saturday week, by which nine persons lost their lives and a large number were severely injured. The accident took place in a percussion cap manufactory belonging to Messrs. Walker, and situated in Graham Street. The work was chiefly done by women and young persons, and they were met to receive their wages when the explosion took place, burying employers and employed in a common ruin. There were five of the family of the proprietors on the premises at the time of the catastrophe - three sons and two daughters ... The building was completely destroyed and the adjoining property seriously injured. The cause of the explosion remains a mystery. It appears, however, from the evidence of the survivors, that the percussion powder was kept in an iron safe in

the cellar of the premises, and that shortly before the occurrence, one of the Messrs. Walker went to the woman who had charge of the mixing and filling department for the key of the chest, and then he and his brother went down to the cellar..."

Illustrated London News
5th July 1862

There is no mention of any manufacture of mercury fulminate on the premises. But, intuitively, it is suggested that the probable practice would be for a 'manufacturing chemist', of which there were many in our cities until a very few years ago, to make mercury fulminate in bulk for supply to a number of small manufacturers. The making and filling of caps looks to have been labour intensive; while the making of the fulminate, even in considerable bulk, was a limited and specialist job, and also one where it was desirable that the plant be kept in regular use. Birmingham at the time of the accident described above was a noted centre for the production of cheap 'trade-guns' for the West Africa trade. Also the American Civil War was at its height so that it is likely that there were many small manufactories of the kind described.

The Principal Application of Mercury Fulminate

The application of mercury fulminate to the initiation of chemical explosives is almost certainly the most important advance in the development of explosives technology.

The contribution made by the fulminate cap was twofold. The use of a blasting cap allowed the full and complete combustion of a charge of explosive. It also made it possible to initiate explosive reactions in compounds which were ordinarily too stable to be exploded by any other means. The introduction of such explosives as T.N.T. was unlikely to have been possible without the availability of a suitable initiator. Lead azide, for example, the next most practicable fulminate, did not come into general use much before the beginning of the First World War.

Alfred Nobel, whose biography is too complete to bear much repetition here, is generally credited with the invention of the mercury fulminate blasting cap. It was in 1864 that it occurred to Nobel to use mercury fulminate in combination with black powder, and later on with a chlorate, to initiate his blasting oil. But Nobel had first used another 'patent igniter' which is said to have consisted of a glass or metal tube filled with black powder and fitted to the end of a length of safety fuse. The patent igniter worked more or less well with Nobel's blasting oil but it was subject to occasional failure, and, less permissible, it sometimes left unexploded material in the borehole.

It will be seen that all the exterior essentials for the blasting cap had been assembled beforehand - all that was required was the substitution of the fulminate mixture for the black powder.

The given date of 1864 for the beginning of Nobel's work on his fulminate detonating cap implies that he was working on the cap and dynamite (or at least on an explosive made from nitroglycerine and some absorbent substance) roughly at the same time. Yet Nobel waited for fully three years before he secured his invention with an English patent. This is remarkable in a man known for his astuteness in the commercial development of his ideas. It can be suggested that the delay was owing to the sudden loss of faith in nitroglycerine. In many ways the events of 1864-65 parallel the early disasters and delays encountered in the development of gun-cotton. A major explosion in which Nobel's youngest brother, Emil, was killed, occurred at the firm's Heleneborg laboratory. Soon afterwards there were accidents when the liquid explosive was used in blasting in Panama, in Australia, and in San Francisco. There were devastating explosions in Nobel's German and Belgian Factories. Opinion turned against the use of nitroglycerine, as it had against gun-cotton.

* See Ch. VI.

There was a failure of commercial confidence in nitroglycerine as an investment proposition. It was not until the end of 1864 that the Swedish financier, J.W. Smitt, invested the money needed for a new factory at Vinterviken near Stockholm.

This crisis may have caused the delay in Nobel's work on the blasting cap and thus account for his delay in taking out his English patent.

It may also be the case that while the full utilisation of nitroglycerine was dependent upon the invention of the blasting cap, the widespread use of the blasting cap depended upon the invention of dynamite. Had there been as long a period of public mistrust in nitroglycerin as there had been for gun-cotton - had he not invented his dynamite - then the blasting cap would have wanted for an application.

Alfred Nobel's English patent (No.1,345) is dated 7th May 1867. But there is some evidence to show that mercury fulminate caps were in use elsewhere for some years before the idea was secured by a patent. The Engineer of the 12th May 1863 contains a short article describing current Swedish practice:

"The process is very easy: if the chamber of the mine presents fissures it must first be lined with clay to make it watertight; this done, the nitroglycerine poured in, and water after it - which being the lighter liquid remains at the top. A slow match (safety fuse) being introduced, with a well charged percussion cap, at one end is introduced into the nitroglycerine."

But very much more importantly from the point of view of showing the course of development of mercury fulminate in blasting caps is a recollection by a British civil engineer of an even earlier use of fulminate caps to initiate explosions. The occasion is the discussion period following on from the reading of a paper by Sir Frederick Augustus Abel to the Institute of Civil Engineers in 1880.

"Mr. Andre:

The Author of the paper* (F.A. Abel) had gone back to the year 1869, when experiments were made on the detonation of gun-powder; but in the year 1854 General Picot published a work on the Art of Siege Warfare, and in which that he advocated the detonation of gunpowder by means of fulminate of mercury detonators. He said: 'For detonators we used copper cases eleven millimetres in diameter, containing one gramme of cap composition, fitted to the end of Bickford safety fuze... Long continued use of these caps showed that for a given effect we might reduce the quantity of powder by one third, or with equal charges obtain the greatly increased effect ... this mode of firing has important advantages..."

The article on explosives in the 1870 edition of Spon's Dictionary of Technology describes and illustrates what is in all its essentials a modern high explosive charge: purpose prepared, initiated by a two-stage primer containing a fulminate and an initiating material, and needing no stemming.

The method described is that for gun-cotton, and therefore, although no reference is given in the text, it is very probably taken from the specification of Brown and Abel's patent. The use of an initiator of dry gun-cotton - which allowed a main charge of wet gun-cotton to be exploded is significant.

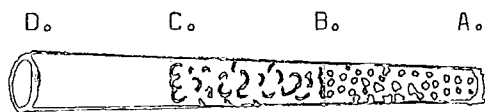
"The mode of operation is as follows:-

The detonating substance is placed in a tin tube of the dimensions shown..."

(The engraving used in the source article is reproduced here rather than in an appendix, since it is very simple and can be taken in at a glance).

*The Discussion Section of Paper 1712
"Explosive Agents applied to Industrial Purposes" by Frederick Augustus Abel, C.B. F.R.S. C.E. 23rd March 1880.
Proceedings of the Institute of Civil Engineers

Length: 2 inches (5 cm.)



"and it occupies in the inside of the tube the space from A to B (the mercury fulminate).

On this at C is placed a small plug of gun-cotton, and the rest of the tube from C to the open end at D is empty.

Before leaving the manufactory a small piece of paper is pasted over the end merely to prevent anything falling into it, and this paper, so long as it remains, serves to distinguish the charged or useful primers, as the tin tubes are called, from the empty tubes.

It is in this form that the detonating primers are supplied from the manufactory.

These primers are, in fact, large percussion caps, and are handled with care, as also to be protected from fire, and from all violent concussion... They may not only be safely handled, but may be thrown about with any freedom short of actual and intentional violence..."

To prepare the primer for use it was necessary only to remove the paper plug and insert the end of a safety fuse until it came into contact with the dry gun-cotton. The tube was then pressed close to the fuze by means of a pair of common pliers.

This particular kind of primer was intended to be used with Abel's pulped and compressed gun-cotton:

"The charges of compressed gun-cotton are made with a circular hole to receive the fuze. Into this hole the small end of the primer is inserted, instead of the fuze..."

British endeavour had been expended in finding a means of initiating gun-cotton. This line of effort was in keeping with the competition which had taken place between Nobel, with his dynamite (and his associated detonating cap), and Abel, and his supporters, with their gun-cotton.

The two very similar kinds of detonating cap were discovered at very nearly the same time. However, Alfred Nobel must be allowed to have brought out his primer first. Nobel's patent was British patent No.1345 of 1867, while Abel and Brown jointly took out British patent No.3115 of 1868.

There was in point of fact very little difference indeed between the two kinds of detonating cap. The wording of the specifications is interesting because it seems that neither of the protagonists was inclined to take in as wide a description as patentees were usually wonted to do:

(Nobel)

"The detonation of nitroglycerine in the form of dynamite, under all conditions of confinement or non-confinement by means of a strong fulminating cap..."

(Brown and Abel)

"... applied to gunpowder, gun-cotton, and other explosive compounds, when in an unconfined state..."

(Engineering for 28th April 1871 gives a more than ordinarily detailed account of Brown's work with gun-cotton and fulminate detonators).

It can also be said that Nobel demonstrated his detonator a good deal earlier than Brown and Abel:

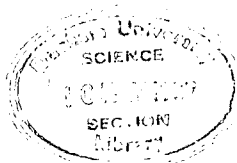
"Mr. Nobel used his percussion fuses at the Merstham experiments in July of 1868, whilst the experiments with gun-cotton exploded in the same way were not carried out until 22nd January 1869..."

Engineering, 22nd September 1871

Mercury fulminate detonators, blasting caps, passed very quickly into commonplace use. The form of the cap, well before the turn of the century, became more or less standard: a seamless tube of nickel-plated copper charged with a precise amount of fulminate of mercury and ready to be crimped on to the end of a length of Bickford fuse or the leads from a magneto.

The Rare Use of Silver Fulminate

Within a considerable corpus of printed source material, only a single instance of the use of any substance other than the fulminate of mercury as an initiator for explosives was found. The single instance, which occurs in a paper of the Royal Netherlands Institute of Engineers,* cites the use of caps containing 62 grains (4 grams) of the fulminate of silver as being used to detonate charges of both gunpowder and Lithofracteur in the blasting of pack-ice from navigation channels. But no reason for the choice of the silver based compound is given, and no remark is made of its efficiency or otherwise. The only reason that can be suggested for the use of silver is that it may have been readily available on an occasion when mercury was not: it may have been a makeshift.



* Tijdschrift van het Koninklijk Institute van Ingenieurs, 1876=77, pp.1=8.
Printed: Proc.Inst. C.E. Vol. LV., p.384, 1877.

CHAPTER 3

BICKFORD'S SAFETY FUSE

A. Preliminary Qualification

William Bickford (1794-1834) is generally credited with the invention of the safety fuse which has been closely associated with his name. This association has been assumed in all save one of the printed sources - many of them contemporary - so far consulted. A single source casts doubt on William Bickford's claim to be the inventor of the first safety fuse.

Before going on to discuss the history of the technical development of the Bickford fuse, it will be necessary first to present this contrary evidence, and then to offer a limited evaluation of it.

The single source of doubt found comes from a digest of law reports published in 1851.^{*} Among the cases cited to illustrate points of United Kingdom patent law are three reports and a synopsis concerning protracted litigation entered into between 1838 and 1839 by Bickford et als against Skewes to obtain, in the first instance, an injunction to prevent Skewes from manufacturing and selling safety fuses.

Because the law reports are long, and because they are couched in the legal language of more than a hundred years ago, only those portions which concern the identity of the inventor will be quoted.

The first indication that William Bickford was not the true inventor of the fuse he patented comes from a synopsis given as a guide at the beginning of the collection of cases. The points it is wished to emphasise will be underlined.

(a) "... the defendant (Skewes) applied to the Court to have the injunction dissolved on the grounds that the plaintiffs

^{*} Law Reports and Cases, by William Carpmael Esq., Vol. II, p.459, et seq. Printed and Published by A. MacIntosh, 20 Great New Street, London, 1851.

did not invent the particular manufacture, but purchased the invention from an Irishman, whose name was unknown to the defendant; and that there had been no long enjoyment by the plaintiffs, and that the bill of specification left it in doubt whether the patent was for the fuze or for the machinery for making the fuze..."

And later on in a case digest:

(b) "The Vice Chancellor - The Court sets the fact of the enjoyment against the legal objection either of the badness of the specification or the fact of the patentee not being the inventor..."

And yet later again in an exchange between Lord Chief Justice Denman and Mr. Sergeant Bompas:

(c) "Mr. Sergeant Bompas - In support of the plea that the invention was not new, the evidence showed that there was an Irishman who went about selling exactly the same fuzes, that he fired them under water. This was in Redruth, in the very centre of the mining population. Many persons saw them and took them in their hands; they were in the form of a cord, they undid them, and saw the powder. It is clear that the patentee must have got his invention from this previous public use, and a patent under such circumstances cannot be valid."

The plaintiffs (Bickford et als.) had no strong counter case to offer. Mr. Justice Coleridge at the Devonshire Assize:

(d) "I thought this all a matter for the Jury. There was a great deal of negative evidence on the part of the plaintiffs; they called a great many experienced miners who said, that, until this invention, they had never known anything like it."

Mr. Sergeant Bompas again:

(e) The witness Trengrove said:- "I saw the Irishman ten or eleven years ago in the western part of the mine. He had some safety rods with him, which he offered to the men going underground. He touched one end with fire - the powder took light - burned all through from end to end - he threw it into the water - he stamped on it, and threw it about - there was no putting it out. Outside

it was hemp, bound round just the same as we are using it now; too, much resin or tar about its outside. I saw no difference between it and the 'safety'." Then your Lordship will find that the witness Clement said:- "I am a miner at Cambourne; reared there, and worked in the mines in the neighbourhood twenty years; worked at North Roskier. Whilst working there a man came round; they said he was an Irishman; about ten or a dozen years ago; saw him with a thing for blasting mines; it was made of hemp or twine, just the same as what the 'safety' is made of now. I do not know particularly what part of the mine I was in when I saw him there - near the shop, but I cannot say exactly where it was; I had two of them in my hand about eighteen or twenty inches (51 cm.) long; we carried two underground, put it into a hole, opened the end of it, lighted it; it went off very well; he had several more pieces, but I did not see him do anything with it. I saw Bickford's. I know no difference between the two; they burn in the same way.

Mr. Thomas Davis worked there when I had this from the Irishman; we were talking to one another about it; he said there could be little improvement.

I saw the Irishman in the public house the same evening; he had plenty of these things with him there, they were tied round in a bundle."

(f) Supposing this evidence to be believed, I submit there was a public use. The true principle is this, in order to ensure that when a person takes out a patent he shall be really the inventor, some precaution is necessary that he should not have had the means of learning it from others. There is every reason to suppose that Mr. Bickford obtained this invention from the Irishman and the Learned Judge should have told the Jury that there had been a publication, and a public use of the invention before the date of the patent. There is no doubt that there was such a person as the Irishman; this was agreed by the witnesses on both sides, and there was some evidence to show that Mr. Bickford entered into some agreement at a public house with that person. This is all strong evidence for the defendant, and the Jury should have found this issue for the defendant.

Finally, Lord Chief Justice Denman: (On the above points):

"... but with regard to the verdict being against the evidence, my brother Coleridge is of the opinion that the Jury exercised their judgement on the subject. I have not the least doubt it was left fully to them to exercise that judgement, because it is clear otherwise, it would have been a mere absurdity to ask their opinion on the effect of the evidence."

That William Bickford was entitled to be considered to be the inventor of the safety fuse was a matter determined by an Assize Jury in a piece of civil litigation. Accordingly, in law, he became so. And in consequence of that verdict for anyone thereafter to have challenged his title could have lead to further expensive court proceedings.

It is also necessary to be reminded that at the time of the Assize (Summer 1839) William Bickford had been dead for almost five years. He was not, therefore, able to give his own testimony. The action was brought by William's son, John Solomon Bickford, and his partners, Smith and Davey, for the sound commercial reason that they wished to protect their patent against infringement. Filial piety aside, there was altogether more at stake than the question of the primacy of the inventor.

An additional complication presents itself. If the first spark of invention did not flash in the brain of William Bickford then there is - for want of a candidate whose identity is known - no other person to whom the invention may be attributed.

The observation is here made that this was a matter of technology and was settled quite quickly, and for ordinary purposes finally, at law. Had it been a matter of science, a dispute between say, chemists on some points of theoretical interest, then the matter might not have been settled even to the present. It is easy to see, and reasonable to speculate, how it came about that William Bickford was allowed to rest in his primacy: nobody at the time was greatly concerned.

For present purposes then, it will be allowed that William Bickford was at the very least the developer of a very good idea. Whether he was

the actual inventor or whether he simply had the wit to recognise and purchase a promising property will be left open.

It may be no accident that this particular case was chosen for inclusion in a collection of cases intended to show the complexities of patent law. Mr. Carpmael, the compiler, was a lawyer, a Member of the Honourable Society of Lincoln's Inn; but he was also a Member of the Institution of Civil Engineers. Indeed Mr. Carpmael addressed the Institute at the very same meeting at which Colonel C.W. Pasley read his own paper on the use of Bickford fuse in underwater work.

Some further study of the legal record relating to the cases of Bickford et als V Skewes (Q.B. 938 ; 4 My. and Cr., 498; Webs.R., 211-214), particularly by someone with the legal training to read them aright, could well lead to some more definite historical conclusions.

(a) "I embrace in the centre of my fuze, in a continuous line throughout its whole length, a small portion or compressed cylinder, or rod of gunpowder ... and which fuze so prepared I afterward more effectively secure and defend by a covering of strong twine made of similar material (Hemp) and wound thereon at right angles to the former twist..."*

The specification of British patent (No.6159) dated 6th September 1831, is deceptively simple and straightforward in its wording. It is at first reading hard to see what it was that the Cornish hide merchant was trying to patent that was so novel at all. Fuses of one kind or another were at least as old as gunpowder itself. And indeed William Bickford goes on to acknowledge that fact fully in the same specification:

(b) "... and I use them either underwater on on land ... as occasions require, in manner long practised and well known to miner and blasters of rock."

It was not so much a fuse that William Bickford had patented - it was a way of making fuses.

* Spon's Dictionary of Engineering, E. & F.N. Spon, Ed. Byrne, London 1870, 1607, et.seq.

Bickford's patent contributed what could be called an enabling process. It made possible for the first time the production of a uniform product, in quantity.

It is not usual to conceive of a consumable like fuse cord in the same way that we might of interchangeable metal parts in machines, but it here suggested that Bickford's fuse was as important a contribution to standardisation, in performance, as anything contributed by mechanical engineering.

With the advent of a reliable safety fuse some at least of the almost mystical lore attached to the use of gunpowder for blasting became redundant. A miner thereafter could broach a parcel of fuse and anticipate with reasonable confidence that it would burn at a certain speed, a certain approximate speed, would seldom hang-fire, and so on. The specific qualities the new fuse offered will be examined in detail presently.

The advantages which the new fuse brought were quickly appreciated by men who had in other ways been for many years attempting to solve the difficult technical problems associated with blasting. Bickford's fuse may have made possible work which was just beyond technical feasibility with the older methods. At the very least it made easy tasks which had before been uncertain and difficult. It should be remembered that at the time of the invention of Bickford's fuse black gunpowder was still the only explosive in practical use - a simple conflagrating explosive.

The enthusiasm with which the fuse was welcomed is best illustrated by the somewhat wry comments of Colonel C.W. Pasley of the Royal Engineers, an officer whose career closely paralleled the development of the new explosives, and particularly their application:

"Here have I, with the Arsenal (Royal Laboratory) behind me been all these years trying to scheme a safe and simple means of conveying fire to the blasting charge, and never thought to make

black gunpowder burn slowly and regularly, which a Cornish man has discovered in a rope-walk."*

Colonel Pasley might well have expressed surprise. But it was perhaps because the Cornishman had spent time in a rope-walk that he was able to approach the problem differently.

The invention of the safety fuse yields two examples of not uncommon phenomena in the history of science in general, and of technology in particular. On the one hand there was the existence of a blindspot in the ideas of one group of workers, which perhaps was derived from their being too close to the problem. In this case the military engineers, pyrotechnists, and powder-makers may have been pre-occupied, had a fixed 'set', which caused them to approach the problem, as it were, from the gunpowder end. They had been long concerned either to get the gunpowder into the protective casing from one end, after the casing had been prepared, as with straw, reed, or paper fuses; or they had tried to hold the powder column in place by having the powder grains stuck first to a central cord. As will be seen presently none of the approaches to the solution of the problem could quite offer the advantages that the introduction of the Bickford fuse brought.

Only the powder hose used by the military for destructive demolition could be said to have approached the problem from about the same direction. The powder hose was a leather tube filled with gunpowder. The leather was folded along its length to form the main tube and then, at the open side, folded over yet again to give a fourfold thickness along the seam. (This is conjecture, but it is suggested that the method of sewing used would have been that of the saddler where two needles are used, to cross each other's paths down the seam; this allows the seam to be pulled very tight).

The powder hose could be filled as the seam progressed; which is why

* The Rise and Progress of the British Explosives Industry.
(VIth. International Congress of Applied Chemistry: Explosives
Section) London: Whittaker & Co. 1909, p.117 et seq.

it could be said to have come closest to the Bickford fuse in its conception. The powder hose would, of course, have been extremely prodigal of gunpowder because of the difficulty of making a very thin tube with hide.

All of these approaches to the solution of the problem were beset by at least two sets of limitations. There were limitations on the size - the natural size - in which the raw materials came to hand in those times. This must surely have imposed limits on the way that people thought - could sensibly think - about their materials. A hide for example, even when cut spirally, would only give so many meters of leather strip. There was in addition the problem of the seam. It should be remembered that the problem of producing a seamless tube was not solved for any but the most tractable of materials until well into the present century.

There was also the very important limitation on the simple nimbleness of human fingers. Fuse making was an uncertain business when done by hand, and the output could never have been high. Quantity production waited on the introduction of a machine. The bringing together of twelve strands of yarn, the twisting of them together so that they enclosed a fine and continuous thread of powder, was a job beyond human dexterity.

The second of the phenomena suggested is that of scientific or technological 'cross-pollination'. The inventor may have hit upon his solution to the problem because of his natural 'set' towards rope-making. Added to this there is the fact that he lived in a mining community where powder was much used and there were many accidents due to its improper use. This is seen as the obverse of the limiting set of the military engineers.

Chains of loosely deductive reasoning about the nexus of contributing factors as to why a given discovery is made at one place and not another, at one time and not another, are not often sustainable. But in the case of safety fuse some outstanding factors do advance themselves very strongly:

(i) Cornish metaliferous mining is mining in hard rock; therefore there was an impetus to adopt gunpowder early.

(ii) The value of the metal won relative to the quantity of gangue mineral to be brought down was high; therefore gunpowder would be used extensively because the enterprise would bear the cost.

(iii) In metaliferous mining it is necessary to follow the lode wherever it leads; therefore the miners would have the problem of firing shots at all angles.

(iv) A charge in hang-fire rendered the gallery unworkable for an appreciable time and therefore represented a loss to both miners and masters.

(v) A dead or incapacitated miner tended not to be easily replaceable because labour was not greatly mobile. He also represented a charge on a community with small surplus wealth.

The Precursors of Safety Fuse

Only by looking first at the principal ways in which a charge was fired before the introduction of Bickford's fuse can the advance made be fully appreciated. A brief survey of these methods will now be given. It is not difficult to see that they were all more or less dangerous.

The Powder Train

A simple train of spilled gunpowder grains was the earliest means of setting fire to a powder charge. The most obvious disadvantage is that the train was subject to interruption by damp or draught. It was fast in its action. Most importantly, a powder train could not by itself rest on a ~~steep~~ incline.

The Simple Fuse

At its most simple, the fuse is a powder train which has been enclosed in a protective and supporting coating, and, as has already been mentioned, the difficulty with fuses lay in the general unavailability of sufficient lengths.

The Miner's Squib

This ingenious but extremely dangerous method is most lucidly described by a near contemporary account taken from a professional journal. It is noted that Bickford's fuse had been in use for seven years when this paper was read.

The bit or iron rod, called a jumper, is generally used. In pitching a deep hole, a two inch (5 cm.) bit is used for about four feet (1.22m.), and a seven-eighths (2.22 cm.) inch bit for the next four feet (122 cm.), by one man; then two men are employed with one and three quarter inch (4.5 cm.) bits to the depth of fourteen feet (4.27 m.), and a one and five eighths inch bit (4 cm.) to the depth of twenty-one feet (6.4 m.). A constant supply of water is required during boring the hole. The hole being well dried, about one third is filled with powder, say fifteen pounds (6.8 Kg.); a needle is introduced as far as possible without driving it; the hole is then tamped with dried clay to the top, and then covered with a little loose clay to prevent any loose particles falling in when the needle is withdrawn. A reed, filled with powder and split at the top to prevent its falling to the bottom of the hole, is inserted, and a stone laid upon it; the powder being ignited by a piece of touch paper and a train, the reed flies to the bottom of the hole, and ignites the main load.

The rock is generally cracked and loosened to a considerable extent, if not thrown in; in that case the needle is driven through the tamping and a fresh charge is run through the needle hole as may be requisite. From six to eight tons of rock (6.096 tonnes - 8.128 tonnes) are generally blasted with one hundredweight (51 Kg.) of gunpowder.

On The Limestone Cement and Method of Blasting,
in the neighbourhood of Plymouth, by W. Stuart,
M. Inst. C.E.

The above passage serves well to illustrate the problems which attended the bringing about a blast without endangering the safety of the operatives. The hazards look to have been centred mainly about the consequences of a misfire.

The need to use the dangerous squib method is plain: the charge at its nearest access stands fourteen feet from the surface. A fourteen foot long fuse made from straws or reed sections jointed together would introduce a high failure rate if the fragile fuse were even a little damaged during the stemming-in.

The use of the squib requires that the bore-hole be vertical and downward. This would be by no means always the orientation in a mine where there was a vein to be followed at the most economical line of approach.

The Advantages Offered by the New Fuse

Having reviewed briefly the difficulties and limitations that went with the main methods in use before the safety fuse became generally available, it will now be appropriate to look at the advantages the invention brought.

The Bickford fuse would have been strong. The twelve strands of jute or hemp yarn would have been every bit as mechanically strong with the powder core as without. The main advantage here was the fuse could bear its own weight even when hanging in a long loop. It is probable that even when a fuse had burned along its length its tenacity would still not have been much reduced.

Because the gunpowder was so thin and so compacted, and because the protective covering was so relatively thick and tough, the fuse was robust; it could, for example, be stood upon without its being either damaged or having the flame put out.

The flexibility the fuse stood to have been useful in some situations.

Bickford's safety fuse came most usually in twenty four foot coils. The advantage of having for the first time readily available, unjointed, long lengths of fuse would have been readily appreciated. The appreciation would have been dependent upon the fuse being reliable along its entire length.

But by far and away the greatest advantage of the safety fuse was that it offered a predictable and consistent rate of combustion.

By a recent circular the maximum rate of burning of a coil ... is fixed at six minutes for twenty four feet (7.3 m), or forty-five seconds per yard (91 cm.), and the minimum rate of burning at ten minutes, or seventy five seconds per yard. The rate of burning of the fuze in each cask* is marked on the outside, a margin of five seconds over or under the specified rate being allowed. If the burning rate of any piece of Bickford's fuze is not known, it must be remembered that it may burn as quickly as four feet (122 cm.) per minute.

Instructions to Military Engineers

Sec. 23, 1870

School of Military Engineering

Chatham. By C.W. Pasley

War Office Pub.

Horseguards, London.

How the Fuse Worked

Perhaps the above quotation should cause a modification of the statement about the predictability of the safety fuse's rate of combustion; perhaps it should be altered to relatively predictable. There was nothing at the time with which it could fairly be compared. At the very worst it could be said to be so much better than anything available before. The

*Fuse for the military was delivered in casks; for the civil market it was sold in 'parcels'.

important question is how was this slow rate of burning achieved?

Size of grain, compaction of train, diameter of the powder core but it would be difficult to say with any conviction which was critical. It should, however, be said that none of the sources consulted has ever indicated that any inhibiting substance has ever been used in the core of a safety fuse: the end was always achieved with common black gunpowder.

For the present it will be useful to apply some common-sense insight in the way the Bickford fuse works in the way it does, so remarkably differently, so much more slowly, and yet so much more reliably than other simple fuses.

Consider a hollow reed filled with grains of gunpowder and ignited - the most simple kind of fuse. Allow also that in this case the powder grains are very coarse. Looked at closely this is a column of gunpowder grains, enclosed and with air spaces between the individual grains. In terms of the volume of the case the air spaces might represent a quite large proportion of the total.

It was known at least as early as the beginning of the nineteenth century that a single grain of gunpowder was capable of igniting another single grain of gunpowder at up to eight diameters distance in the open air.* This might allow it to be said that loose gunpowder with air spaces between the grains would burn quickly because one grain would readily be able to ignite another in a sort of domino effect. In the confines of fuse walls there might be the additional factor that the burning powder would generate pressure to speed the process.

Closely packed but finer grains, on the other hand, would have progressively more but also smaller and more isolated air spaces. The burning surface of any grain in a close backed column would be inhibited by its next neighbour That is to say, before the burning face in the

* Nicholson's Dictionary of Architecture, London, 1818.

fuse can advance it must consume the powder which lies in its way, as it were, serially.

In referring to close packing in powder grains a distinction is drawn between close proximity and actual compaction. The former is meant.

Such information as has been found on the size of powder grain used in fuse making indicates a grain size that would pass through a sieve with forty meshes to the inch (2.54 cm.) as the largest permissible size, and a grain size to pass through a sieve with eighty meshes to the inch (2.54 cm.) as the smallest.

It is observed that relative to the size of the powder grains in the core, the fibres of jute or hemp used would be of a quite appreciable size. They would also, it is visualised, intermix with the small powder grains along the course of the core, taking up some of the remaining air spaces; but more importantly, these small fibres would stand in the path of the advancing burning face, and there take up a small but significant part of the oxygen liberated in the burning. The smaller in diameter the powder core, the greater the relative effect of the intermixed fibres is likely to have been.

The 'lay' of a rope is not straight. If a number of cords are twisted together, the central cavity left will tend towards a shallow spiral. This can be demonstrated by twisting four or more short lengths of clear plastic tubing into a handspan of rope. If a further length of coloured and much thinner plastic flex is then put into the centre position to represent the powder core, when the tubing is again twisted together the path of the 'core' will be seen to undulate when viewed from any angle; it spirals. The core of a safety fuse would, then, appear to be actually somewhat longer than might at first be thought. In comparing the rate at which two different fuses might burn, it is possible that the diameter of the core itself might affect the speed of burning: the larger

the diameter of the core the faster the rate of burning, because the larger core made for a shorter burning.

The 'Spit'

The 'spit', that is to say the terminal spurt of flame which results when the last part of the burning surface approaches closely to the end of the fuse and is thus able to blow out of the unconfined end of the casing as a spurt of flame, afforded an extra impetus to the ignition of the main charge. The 'spit' of fuses only became an object of interest and research when concern for the safe use of gunpowders in gassy coalmines grew later on in the nineteenth century. A too long 'spit' was likely to cause gas explosions; a too short or feeble 'spit' meant that the fuse was unreliable. (Incidentally: this concern with the 'spit' might be taken as evidence that gunpowder was the sole core material ever used in safety fuse. The introduction of the various kinds of Permitted explosives would have been for nothing if hot burning gunpowder had been introduced into gassy mines in the core of safety fuses).

The Process of Manufacture I

It has been thought useful here to treat the manufacture of safety fuse in the initial stage of its development in some detail. The reason for doing so is pragmatic. It is wished to make clear and easy to understand a small corpus of source material which it is believed suffers much from poor exposition. There has been found to be no scarcity of material about the purpose-made machinery which came into use later in the century. However, there has been found, so far as this study has been able to go, little which shows clearly the way in which safety fuse was made during the years immediately following 1831. Moreover, the material which has been found -- it amounts virtually to a single main source -- is not easily understandable.

The single source is an article in a technical dictionary of the year 1870.* The article is at best badly done editing work; the text is a patchwork of portions of patent specification widely disparate in time; the notation of letters given in the text does not always have referents on the engravings illustrating the text; the engravings themselves do not illustrate the text accurately, nor are they drawn in any proportion which can be related to the text.

What has been done with this source has been, first of all, to make a clear copy from a faded text printed in minute type. The redundant letter notation has been removed, as have the worst of the patent specification's circumlocutions. The portion of the text which refers to the patent of William Bickford has been abstracted from that which deals with the later patents of Solomon Bickford and his partners. What it is hoped results is a series of paragraphs which will describe, with some economy, William Bickford's 1831 fuse making apparatus.

(a) "At the left-hand end of an apartment, which is 65 ft. (19.8 m.) long, is made an enclosed recess or closet of about 2 ft. (61 cm.) square and 6 ft. (1.83 m.) high, with a door or doors in front; in which closet, at a height of about 4 ft.10 in. (1.47 m.) is placed a wooden shelf, about 1 in. (2.54 cm.) thick at least, extending the whole length and breadth of such closet."

Three observations are made on this section:

(i) The left hand end of the apartment is specified because the machinery was to be hand-operated - most of the operatives would have been right-handed.

* Spon's Dictionary of Engineering by E. and W.F. Spon, Ed. Byrne, London 1870 (p.1067) et seq.

(ii) The purpose of the door or doors cannot be more than guessed. Secrecy could hardly have been long maintained when more than a few workers were employed. At first sight the doors would appear to do nothing but hinder the operative.

(iii) The length of the walk being specified at sixty five feet excites most speculation. It may be that the length has something to do with the spinning of cordage and has its origins in the history of rope-making. With an allowance of seventeen feet (5.18 m.) to spare for working space, the walk would be able to make forty eight feet - two coils - on a single run. It may be that even with the lightweight of line with which fuse making worked that after forty eight feet the drag and the hang of a long loop of fuse became cumbersome. Perhaps the best guess is that forty eight feet was the longest length that could be easily dressed, taped, or countered in the later processes of manufacture.

(b) "In the centre of this shelf is made a hole, into which hole is inserted a collar. This collar is of metal, in form the frustum of a cone inverted. It is 3 in. (7.62 cm.) long, 2 in. (5 cm.) diameter at the upper end, and $1\frac{1}{4}$ in. (3 cm.) at the bottom; through the centre of this is a hole $\frac{3}{4}$ in. (2 cm.) in diameter at the top, and $\frac{3}{16}$ inches (.5 cm.) at the bottom... Around this, in a circle, are twelve holes of about $\frac{1}{8}$ (.3 cm.) of an inch diameter, which converge towards the bottom, so as to be separated by it only by a fine wedge of metal..."

(The prepositional idiom used in the last sentence above is recorded as it was printed).

This is the heart of the invention. The collar - or powder cone - is the means whereby the gunpowder and the yarns are brought together. Without the tapering hole in the centre of the collar, the machine would simply have spun the yarns into a fine cord. Brass or copper was the most likely material from which the cone was made. Copper was the most usual

metal used for implements used to handle gunpowder; brass is specified later in the same article for more developed machinery.

(c) "This collar, when so placed in the hole of the shelf, projects both above and below the wooden shelf. In the upper part of the projecting cone or collar is then to be placed a common funnel, 12 in. (30.5 cm.) high and 10 in. (25.4 cm.) in diameter at the top ...; around this funnel, at about 10 in. high from the before-mentioned shelf, is placed a ring made of cane, supported by a small frame of two or more pillars, resting on the before-mentioned shelf."

A ring made of cane would be naturally very smooth and very strong. Such a ring secured loosely to the lathe-turned wooden support pillars would allow a degree of necessary give in apparatus that was processing loosely tensioned yarns. Such an apparently ad hoc arrangement may have been used for the very good reason that it worked.

(d) "At about 2 ft. 6 in. (76 cm.) high from the floor of this room, and passing through the said closet, and extending the entire length of the said room 65 ft. (19.8 m.) long is a stage or shelf or bench; the outside of this stage or shelf or bench has a ledge or raised edge rising 1 in. (2.54 cm.) above its surface, and on a similar raised edge on the inside, rising $1\frac{1}{2}$ in. (3.8 cm.) is a line rack with teeth or cogs, twenty teeth to a foot."

At twenty teeth to the foot, a single tooth of the line-rack would be $\frac{6}{10}$ of an imperial inch across. This may indicate a metal construction. Wooden teeth of the size, even if made from some durable wood like hornbeam which was extensively used for wooden machinery, could hardly have been very durable under heavy use.

(e) "This stage ... is intended to support thereon a machine, being part of the apparatus thus used by me in my invention, called the monkey, which monkey consists first, of a plain piece of board, 20 in. (51 cm.) long and 6 in. (15 cm.) wide, supported

by and turning in two centres, is a traverse axle placed quite across the plane bed of the monkey, supported by brackets and turning round in holes made in the brackets, on the inside end of which there is a wheel of 10 in. (25.4 cm.) diameter."

In the light of the doubt cast on William Bickford's claim to be the inventor of the safety fuse and the apparatus for making it, it is hard not to seize upon the wording above as a further indication of doubt. The exact phrasing has a certain delicacy to it; 'being a part of the apparatus used by me in my invention.' It is almost as though Bickford wished particularly to annexe to or engross within the description of his apparatus a commonly used mechanism. A 'monkey' was no new thing in 1831. In marine useage, a monkey block was a block used in guiding running rigging; in mining, it was a device by which a moving cable was gripped or released; again in mining, it was a block placed between the rails of an inclined plane to prevent waggons from running backwards. The general notion of a something which was used in conjunction with rails or tracks is strong.

It is not possible here to pursue the enquiry further, but it seems probable that William Bickford took into his specification a device commonly used - but not patented. A single instance of a monkey device dating before 1831 would prove the point.

(f) "Close to this wheel, and directly over the line-rack, is placed on the said axle a pinion, which works on the cogs of the line-rack, on the side of which wheel on its outer edge are twenty four teeth or cogs; these teeth or cogs work into the corresponding teeth on the inner circle of the wheel, the wheel having two circles of teeth or cogs, the inner and smaller circle working as already described, and the outer circle of the cogs working into the pinion; connected with this pinion is the crook and into this crook the threads of twine or other material are attached for twisting."

There is no drawing available which matches the above description. A very small and unclear drawing which is part of a line representation of an end elevation of Bickford's original specification gives some idea, but the exact way in which the linear motion is transferred from the line-rack to crook is uncertain; the description is ambiguous. Two drawings will be given to illustrate the above. The first will be an attempt to derive an accurate picture from the given specification. The second will be a representation of a later monkey which carried out the same action but which shows the gear train then used much more clearly. (See Appendix II).

The essence of the monkey device is that it allowed the linear motion derived from towing the board along its rails to be converted into a rotary motion for twisting the fuse as it was advanced.

(g) "A string or cord is fastened to the board of the monkey, and stretching along the stage ... passes over a pulley and returning through holes made in the supports of the stage ... is attached to the winding roller..."

The Task of the Operative

Set against the convolutions of prose used in the description of the apparatus, the account given of what was expected of the operative is relatively plain:

(h) "... twelve balls of twine or other material intended to form the fuze are placed in the recess or closet on a floor raised six inches higher than the floor of the room and running threads from these balls are each led perpendicularly up through holes of one inch diameter made for the purpose in a circle of twelve inches in the shelf in which the before mentioned collar is placed and also perpendicular to and passed from the outside to the inside over the said cane ring next to the funnel hereinbefore mentioned, and from thence the said threads are again led down by the side of the funnel to and through the holes in the upper and under side of the aforesaid collar, and from thence are led to the pulley ... and are made fast to the crook."

From the above given description of how the original Bickford apparatus worked, and by noting the dimensions given, it is reasonable to make some suppositions about the task of the operative.

In the present section it is hoped to show that the task of the fuse maker was neither easy nor simple.

In setting up the apparatus from the beginning of a new run of fuse the operative would first have had to have threaded each of the twelve yarns individually from the bottom of the closet to, and through, the powder cone; after that point, and with sufficient slack pulled clear, they could be taken together over the pulley and to the crook.

(i). "The winding roller now being set in motion, communicates that motion to the monkey, which travels on the stage ... and at the same time by the pinion working on the line-rack ... communicating a turning motion to the crook, completely twists the twelve threads so made fast thereto, and continues that twist up to the very point of the cone projecting downwards from the collar under the funnel; at the same time of putting the monkey in motion the funnel is charged with gunpowder or other combustible matter for making fuze, and it is important then to carefully watch the progress of the threads and to prevent or rectify any entangling thereof; and also to regulate the exit of powder and prevent the dispersion of any surplus that falls to waste through the point of the cone or collar under the funnel during the operation of twisting..."

If the dimensions given earlier in the specification are accurate, then the operative could hardly have worked with any ease at all unless she were a small woman or a child. The right hand of the operative was engaged with the turning of the crank which drew the monkey away along the line-rack. This was purely the supply of a motive force. However, if it were taken into account that the bearing of the axle which continued this crank was stated to be only two feet six inches from the floor of the room, and allow also that the 'throw' of the crank would take from six to

nine inches from that, it will be seen that some stooping would be necessary unless the operative were sitting either on the floor or on a low stool.

But the left hand was required to clear tangles, either below the shelf and in sight, or above it around the cane ring which was out of sight. This would require that the operative reached, or stood up, to clear tangles as they occurred. How often this was necessary is, of course, uncertain.

The monitoring of the feed of powder from the cone is the most difficult to comment upon. There is, for example, nothing shown on any drawings found, early or later, which indicate that the operative had any means of controlling the flow of powder. The orifice was set at 3/16 (.47 cm.) of an Imperial inch.

It is also hard to see how the operative could know with any certainty if there was powder going into the fuse at all. If, as the specification states, '... and continues that twist up to the very point of the cone,' the gap between the die-piece and the tip of the cone was so small it would be difficult for the operative to monitor the flow by sight. The best suggestion that can be offered here is that the operative would be able to hear the gritting of the powder as it became enmeshed in the running threads, or it may be that the flow of powder through the cone gave a distinctive sound that the practised operative would recognise.

Reference to 'the dispersion of any surplus that falls to waste through the point of the cone...' suggests that the fuse maker may well have been working within what was a steady fall of fine gunpowder dust issuing from the tip of the cone, which stood a few feet and a little to the left above her head. During a long shift the cumulative escape may have amounted to a fair covering of loose powder collecting over the yarn

balls in the bottom of the closet, and even over the operative's clothing. The hazard here in the event of a fire is obvious. But to the modern eye the risk of some form of bronchial complaint in long service operatives is glaring.

The writer of the dissertation which in part treats an industrial process should be able to draw on his own experience to give an informed opinion on a matter in which he has special experience. Workers who handle vegetable fibres are prone to cuts, sometimes very deep cuts. Jute comes to mind as an example. Where insoluble substances get into cuts and the skin heals over afterwards, the marks left are quite permanent. Wire 'clicks' from handling rusty steel wires, and the blue-black marks of coal fragments blasted under the skin in coal miners are firm examples. It is posited here with some confidence that the women who worked in Bickford's Camborne factory during the 1830's would be recognized at once by the black tattooed streaks, largely on their left hands, which came from handling hemp yarns in the presence of fine gunpowder dust.

The Process of Manufacture II

The following example will give some idea of the extent of development which took place in the making of safety fuse within sixteen years of its first appearance.

(a) "Mr. Smith of Camborne, Cornwall, has lately patented the application of Gutta Percha, to the manufacture of Safety Fuses for blasting.

The use of the new gum affords an excellent means of protecting the gunpowder from the effects of moisture or the pressure of water, when used for submarine blasting. Mr. Smith proposes to use it either as a simple exterior tube for enclosure of the gunpowder, or he applies it merely as a covering for the ordinary hemp fuse. In the former case, the following is the process laid down by the patentee:-

(b) A cylinder of iron, or other suitable metal, capable of supporting a pressure of 500 lbs. (227 Kg.) to the square inch (6.452 sq.cm.) and made at its lower extremity of the form of an inverted cone, is surrounded with a casing between which and the cylinder, steam is allowed to circulate.

(c) The lower part of the cylinder, that is the apex of the inverted cone, terminates in a pipe, which is carried down through a cistern of cold water. A gunpowder chamber, or funnel is supported by suitable bearings in the centre of the cylinder, and passing through the inverted cone, terminates in the pipe below the joint.

(d) The funnel is filled with fine gunpowder, having a thread through the centre thereof, to facilitate its passage; and the cylinder with gutta percha. The steam is made to circulate between the cylinder and the outside casing, until the gutta percha assumes the consistency of putty. It is then passed through the pipe, and passing round the gunpowder funnel takes the form of a hollow tube, while it becomes filled with gunpowder. The fuse, in passing through the cold water cistern, acquires a degree of firmness, which may be increased by causing it to pass between two rollers, grooved on their peripheries, and made to revolve in opposite directions.

(e) The ordinary hempen fuses are also coated with gutta percha in the following manner:- An iron cylinder, similar to the proceeding, and heated in like manner, is filled with gutta percha, which is subjected to the pressure of about 300 lbs. (147 Kg.) to the square inch (6.452 cm.). The sides of the cylinder are bored with holes of different diameters, to suit the size of the different fuses, to which inlet and corresponding outlet pipes are attached. When the gutta percha is sufficiently softened, a wire, hooked at the end, is made to enter one of the inlet pipes, and, passing through the mass of gutta percha, to come out at the exit opposite. The fuse is cooled in its passage through the exit pipe by an arrangement similar to the one before described."

In one sense this is a new manufacture of fuse altogether; in another it is still the original safety fuse. Coating ordinary safety

* Practical Mechanic & Engineer's Magazine (London) (May 1847)

fuse with a covering of gutta percha to secure the core from the wet is no great inventive leap. But it does show a readiness to adapt new material. The real advance is in the method of manufacture. Extruding a covering of gutta percha, hot, around the powder core, which in turn surrounds a strengthening central thread so as to produce a co-axial fuse has a distinct air of modernity about it. This feeling is enhanced when a later authority, Guttman, writes that, for some German makes of fuse at least, it was the custom to colour code the internal thread so that the factory of origin could readily be identified.

The original reason for this central thread can be derived from a reading of the first Bickford patent. If there had been a problem with the free running of the powder from the funnel through the narrow orifice of the cone before, it would have been much aggravated in the new process. The steam jacketing mentioned would - even under low pressure - almost certainly have caused the sulphur in the powder to soften and cake. This would have been especially likely to occur at the extreme point of the feeding cone where a smaller body of gunpowder was surrounded by a larger body of heated gutta percha. Without the thread, the powder orifice would have been much prone to blockage by heat-coagulated powder grains.

The above process shows an early move away from the adapted rope-making machinery to purpose-made machinery. However, just when this occurred it is not possible to say. The abandonment of the long ropewalk of William Bickford's time probably took place relatively early. Such a method was too prodigal of space to have lasted long. Later texts show machinery which, though still very simple, takes up the fuse on to a reel beneath the machine.

The Fuse in Use

No material dealing with the reception and use of the safety fuse immediately after its introduction has been found for inclusion in this study. However, it may be reasonably assumed that since total output during the first year of production was small, and because the bulk of that output was offered for sale in an area of intense mining activity, it was tried out and, where real advantage was seen to come from its use, adopted.

Consideration of the economic and commercial factors governing the speed with which the fuse was introduced is deferred until a later part of this work, but it is necessary to anticipate here and to observe that during the first few years at least, safety fuse would have been rather more inelastic of supply than of demand. So far as this affects diffusion of knowledge about the new fuse it might be supposed that for some time after its invention it was known by sample and repute rather than by actual use.

In use, the safety fuse was seen as a supplement to other methods, not as a replacement for it. Evidence for this will be presented a little later on in this section. Where the fuse was to receive some attention was in those situations where its use made viable those projects which before had been technically marginal, or too expensive. The use of the safety fuse for underwater work was begun relatively early after its introduction.

Blasting under water had been possible before the advent of the Bickford fuse. But it had been at best an uncertain business. Common gunpowder, being a conflagrating explosive, still needed to be confined, even under water, in order to produce a useful rending explosion. Most of the failings already noted in the use of fuses and powder hose on land

were compounded when it was attempted to use them under water.

The most commonly undertaken projects in underwater blasting were the removal of reefs, the deepening of harbours and channels, and the blowing up of wrecks. The diving bell and, after 1839, the closed diving dress of Augustus Siebe,* were necessary adjuncts to underwater work.

For extensive works such as the clearing of rock from moderate depths, as was done in the deepening of the harbours at Donaghadee and Port Patrick** during 1824-1825, cofferdams had to be built.

How much less expensive such projects became when there was a practical method of blasting under water would readily have been appreciated by civil engineers.

The first series of systematic experiments carried out to test the working efficiency of Bickford's fuses is recorded as having taken place at the Royal Engineers' Establishment at Chatham in the Autumn of 1834. The work was under the command of Colonel C.W. Pasley R.E., who wrote up his findings for the Proceedings of the Society of Civil Engineers.* * *

The Chatham experiments are interesting because they indicate that there was a general search for a solution to the problem of underwater blasting. Many methods - including galvanic ignition - were under trial. But Bickford's fuses were specially commended:

(a) "Great advantage in blasting under water is derived from the use of Bickford's fuzes applied to tin powder cases ... the general practice has hitherto been to ignite the powder contained in a tin canister, by dropping a piece of red-hot iron down a tin tube, reaching to the surface. The tin tubes were liable to failures, Colonel Pasley has used flexible leaden pipes, and a piece of port-fire instead of red-hot iron for vertical explosions. Several other means of firing - as small rockets, a quick match, and small linen hoses - were tried without any great success."

* & ** No.935. "On Improvements in Diving Dresses, and other Apparatus for Working Underwater," by John William Heinke, Proceedings of Institution of Civil Engineers Vol.XV., March 18th 1856, p.309 et seq.

*** "On the Application of Bickford's Fuzes to Blasting Underwater" by C.W. Pasley Col. R.E. Hon member. M.Inst. C.E., Proceedings of the Institution of Civil Engineers Vol.I. April 10th 1838, p.35 et seq.

And again:

(b) "A small fine powder hose, about one eighth of an inch in diameter, secured so as to burn gradually instead of rushing forward and exploding, was found to succeed very well, but was neither so simple nor so cheap as the Bickford fuzes."

This last item, the fine diameter powder hose, is interesting because it shows an independent and parallel development in a general convergence toward a solution of the problem.

Bickford's fuses received the general approval of the professional civil engineers in their journal:*

(a)"After considerable experience, therefore, and the use of nearly 100,000 ft. (30480 m.) of the patent fuse, the author feels that he is doing an act of justice to Messrs. Bickfords, in stating the perfect satisfaction which the use of their ingeniously manufactured material has afforded him."

{It is hard to overlook the niceness of expression the writer uses here, even in a (presumably) unsolicited testimonial: 'ingeniously manufactured'; but not ingeniously invented(?)

And more practically:

(b) "Then as regards cost: the patent fuse No.3, carriage included, cost 6/10 of a penny per foot; if the average length is taken at 15 ft. (4.7 m.) this is just ninepence per shot, a sum which would barely pay for making the arrangement of wires necessary for the galvanic ignition."

The safety fuse may have been quickly and very widely accepted into use in civil and military engineering but a potentially enormous application failed in its development when it was not so generally adopted for use in mines - particularly in coal mines - elsewhere in the country.

* No.725. "The application of Gunpowder as an Instrument of Engineering operations, as exemplified by its use in blasting marl rocks in the River Severn" by G. Edwards, Esq. Proceedings of the Institution of Civil Engineers, 17th June 1845, Vol.IV, p.361.

Natural conservatism in the working miners may have militated against the use of the safety fuse; but men seldom stay long prejudiced against a genuinely advantageous innovation. There is some testimony to show that it was more likely to have been the terms of employment under which the miners worked which prevented the ready adoption of safety fuse: they had to pay for their own out of their earnings.

It is noted that the testimony which follows is all taken from mine managers rather than from the miners themselves.

14,434. (Mr. Thomas Watson, Alston Moor Mine)

(a) "Do you consider that the safety fuze is less dangerous to human life than the other, or more so? - I do not suppose that there is much difference in that way; the danger that I spoke about was stopping the work.

And again:

15,818. (Mr. William Curry, East Allendale Mines)

(b) "Is there any reason why it (safety fuse) should not be used generally? - No; I do not see any particular reason why it should not generally be used beyond the extra cost incurred."

15,819. Do the men prefer the other mode? - Yes, they do.

When men whose earnings depend upon their winning a certain amount of ore, or coal, during a shift have a choice between a swift, if somewhat dangerous method of firing off a shot of powder, and a safer but decidedly more slow method, they would appear to have chosen the faster. Time spent crouching under cover while waiting for a safety fuse to burn down was time which could not be spent hewing out their wages. The use of manufactured fuse, no matter how cheap, was an additional charge against what was probably already a very fine margin.

The miners had a choice - and they exercised it.

14,428 (Mr. Thomas Watson, Alston Moor Mine)

"Do you leave it to the miners to use the safety fuse, or not, as they like in wet places? - Yes."

It is here proposed that the more likely picture was not one of miners' prejudice at all. It seems far more probable that the miners had the wit to work out for themselves, for any given situation, a rough and ready cost-benefit analysis: in an open run of ore, or of coal, it might be deemed more profitable to take a chance on a squib firing. A shift of men would naturally wish to take as much as they could from a stretch of easy working during their own shift, leaving whatever chanced to come along after that to the on-coming gang. Their willingness to use safety fuse in a sump where conditions were wet or partly flooded would reflect a wish to get through uncomfortable work quickly, and a consequent readiness to bear the extra cost.

Complaints about the smell and smoke from safety fuse were at least in part justified:

14,400. (Mr. Thomas Watson, Alston Moor Mine)

"What is the main reason that the men do not use the patent fuse? - Just because of the disagreeable smell."

14,401. "Is more smoke caused by it? - Yes, I think there is from the powder, but there is that from the fuze itself, and that is disagreeable..."

Sump fuse, that is fuse designed to be used in the lower levels of the mine where water tended to collect, would very probably have given off an unpleasant smell. This fuse was usually coated with gutta percha. Since few mines would have had artificial ventilation in the 1840's, the fumes from the burning powder and the smell of burning rubber would have lingered long in the still air of a gallery. Moreover, men doing heavy work would have had to breathe that air deeply. A long

length of coated safety fuse would tend to generate fumes and smoke along its entire length.

The very flexibility which in some situations was a decided advantage could in others lead to the sort of accident the invention had been supposed to prevent:

13,063 (Mr. James Dees, C.E., Parkside Mines)

- (a) "Do you use the patent safety fuze in your mines? - No; and for the same reason that we cannot use the copper pricker. When the patent fuze is used, it is put in with the powder, and the stemming is driven in round the fuze. We have tried it and we find that the fuze is driven into those cavities in the same way as the copper rod is, and it breaks, that is the connection between the firing at the end of the powder is broken off from the irregularity of the bore hole..."

13,064

(b) Why can fuze not be used with safety? - Because of the nature of the ore, being so full of cavities, and those cavities having very sharp edges, so that if the safety fuze was used, the act of tamping would force the fuze into these cavities, the sharp edges of which would cut it and render it entirely ineffectual."

(The danger in the above example would come when it was attempted to stem in a new charge with an iron tamping bar into a bore hole that contained spilled powder grains from the cut end of the fuse).

Some mine managers expressed themselves in favour of the safety fuse but continued to cite the prejudice of the miners as the source of resistance to its full employment:

13,376. (Mr. John Barratt, Coniston Mines (Copper)).

- (a) Chairman: Have you had any accidents from blasting? - Yes.

13,377.

(b)"Is it your practice to use the safety fuze? - Very little, but we have tried it over and over again. I am determined to insist upon it now, because I am convinced of the advantages and safety which result from it, the men are prejudiced against it."

Bickford fuse was not much used in coal mines because blasting was avoided: it tended to rend the coals too much.* But this objection did not hold when shafts were being sunk to reach the coal seams and for this work it was recommended.**

To examine in detail the use of copper and wooden tamping bars, copper pricklers, and the like, would be to take the treatment of Bickford fuse far beyond the proper subject matter of this dissertation. But it must be said that from a study of contemporary reports it would appear that some at least of the benefits claimed for the use of safety fuse should in part be attributed to the adoption of other practices at about the same time.

The testimony given before the Select Committee on Accidents in Mines came sufficiently early after the introduction of Bickford's fuse to give an idea of the true situation and to amplify what has been said above.

165.(John Taylor, Esq. 17th June 1835)).

(a) "... the workman has to fire the hole and then be drawn up by a single rope over it; if the fuze communicate to the gunpowder more rapidly than he expects, he is ~~blown~~ to pieces; but with the safety fuze he may take two or three feet, and so delay the explosion that he may be sure to be in a place of safety before it happens. This is made so cheaply, that no difficulty has been found in its introduction; the men are supplied with it so it is not worth their while to make common fuzes, and I think it is one of the most happy thoughts that has occurred."

(b) 166. "Is that in general use in the mines in Cornwall? - It is used in many of the mines."

(c) 167. "Is it your opinion or not, that its adoption is universal? - I believe it is in general use in many of the principal mines in Cornwall; I have sent specimens to all the other mining districts with which I am connected in different parts of England, but I think it has not met with the attention it has deserved."

* and ** The Winning and Working of Collieries (A Treatise on) Mathias Dunn, Newcastle 1848.

And again:

(d) 172. "You have alluded to three specific improvements, the tamping bar, the needle, and the safety fuze; have you formed any opinion as to the relative decrease of accidents in consequence of the introduction of these improvements? - I cannot say that I can state statistically, or exactly; my impression is that accidents are less common than they used to be."*

The Journal of H.M.S. Enterprise, 1850 - 1855, * * devotes a special note, Note 34: Gunpowder in Ice, to the use of waterproof powder bags and Bickford fuse for blasting out channels in the sea-ice of the Behring Strait. This use of the fuse differs in no material sense from its use in blasting rock or in blasting under water - notionally it is a combination of the two. But what the example does serve to show is that there was a readiness to employ the fuse in novel situations, to expand activity into the areas which the new techniques allowed. It may not have been the first occasion when ice had been moved with gunpowder, but, for want of opportunity, it may well have been the first use of the new safety fuse in the blasting of sea-ice several metres thick on a large scale.

It is noted in the above account that the Navy had to rely on the advice of Captain R. Stothard of the Royal Engineers for the fitting out of the expedition in respect of fuse and powder. The Captain did not, however, accompany the expedition and it is mentioned pointedly that the technique for use was perfected during the voyage by Admiral Sir L.M'Clintock.

The use of watertight containers and safety fuse allowed underwater demolitions to become commonplace: ***

* Report from the Select Committee on Accidents in Mines together with the Minutes of Evidence and Evidence Index, Ordered by the House of Commons, to be printed 4th September 1835.

** Journal of H.M.S. Enterprise, 1850-1855, Memoir of Admiral Sir R. Collinson, Sampson Low & Co., London.

*** No.935. "On Improvements in Diving Dresses, and other Apparatus for Working under Water." By John William Heinke. Proceedings of the Institute of Civil Engineers, 18th March 1856.

The bow of the brig William was found to be still standing in a compact mass, eight or ten feet (2.44 m - 3.05 m.) above the bottom, and part of one side was also remaining. These were subsequently blown to pieces by seventeen small charges of forty five pounds (99 Kg) each contained in five gallon (22.7 litres) tin oil-bottles, and fired by pieces of Bickford's fuzes six feet (183 cm.) long.

The above operation took place on the 6th June 1838. It could with very little modification in method or materials have taken place at any time throughout the rest of the century. The introduction of dynamite and blasting caps did not alter the use of Bickford fuse for simple and limited blasting operations.

The Commercial and Technical Development of the Fuse

The economic conditions coming together to allow the commercial potential of the Bickford fuse to be realised would seem to have been generally very favourable.

William Bickford has been described as a leather merchant.* No information has been found which might be used to show the extent of his trade, but his family was clearly well enough placed to be able to derive the fullest advantage from the exploitation of his patent. William Bickford himself did not live beyond 1834. It was William's son, Solomon Bickford, who was active in the commercial and the technical development of the safety fuse.

(Biographical details introduced into a study of this kind must be brief). The following is presented only because it indicates the social standing of the family and because it may be a way of showing a possible link between the firm of Bickford, Smith and Davey and one of the more important figures in the development of explosives).

Solomon Bickford is said to have held a major's commission. It is not known, however, if this is dated from before or after the founding

* and ** R and P of B.F.I. (1903)

of the business. It is less likely though by no means impossible that the commission pre-dates the beginnings of the firm because Solomon could not have been much older than twenty when his father took out the first patent on the safety fuse. William was only forty when he died (1794-1834). Allow then, that Solomon Bickford held an Army commission, and all that implied during the early part of last century. It is unlikely to have been a commission in a line regiment. In Cornwall, in the 1840's there was no line regiment stationed in the county.* The only two military units mustering in Cornwall at that time were The Duke of Cornwall's Rangers, at Truro, and, more significantly, The Royal Cornish Miners. Both were volunteer regiments.

If Solomon Bickford had been a Major in the Royal Cornish Miners some time after about 1833 he would have known of Colonel Pasley and his work at Chatham, and he would have had an opportunity to canvass his firm's product for inclusion in the trials. C.W. Pasley was to be Bickford's professional witness, in 1839, during the litigation between Bickford and Skewes.

Of the rest of the family, little need be said here. William Bickford's daughter married a Mr. George Smith who later became Dr.** George Smith. Mr. Thomas Davey seems to have contributed to the technical side of the firm for his name appears with that of Solomon Davey as co-patentee on a number of occasions. Together these men made up the firm of Bickford, Smith and Davey, which was to manufacture fuse at Camborne until 1947.

From the start, the business seems to have had many advantages: some it had in common with the rest of British industry at the time, others were peculiar to its own location and nature.

In belonging to the new mercantile classes the family had the

* Illustrated Itinerary of the County of Cornwall by Cyrus Redding, Pub. How & Parsons, London, 1842.

** Doctor of Divinity.

knowledge and the means to protect its interests; as has been seen, it could afford to go to law at the highest level. In being British, at that time, there was some special advantage in overseas trading, both within and outside of a growing empire. It was, moreover a period of great growth in civil engineering projects: the introduction of the safety fuse coincides with the expansion of railway building.

The plant for the manufacture of the fuse was to hand in or near Camborne (whether or not William Bickford owned a rope-walk is not at all clear). An existing rope-walk adapted easily to the new process: the modifications needed would have been minimal. This represents a two-fold advantage. On the one hand little capital would have been needed to be found for the adaptation; on the other, the opportunity cost of going into fuse-making was diminished. There was no need to go entirely into fuse making until the demand was known to be there.

The take-off of the enterprise may have been relatively slow during the first few years. It has been said that forty five miles of fuse were produced during the first year of production.* If this is true then the firm turned out fuse with a market value of six hundred pounds (that is in the money of the time, calculated at .6 penny per foot $\times 45 \times 1760 \times 3 = 237600$ ft. $\times .6$ 'd' = 142560; $142560/240 = \text{£}594.$). It is difficult to say what sort magnitude of turnover this was seen to be in the early thirties of the nineteenth century.

The market for the first output of safety fuse was close at hand. Camborne was at the centre of a mining district. But this may have been the cause of some problems for the new firm. In the beginning the scale of manufacture was necessarily small. Therefore, no matter what the demand for the safety fuse had been from the surrounding copper mines there was a limit to the quantity of fuse that could be made - there

* R. and P. of B.E.I. (1903)

was a certain inelasticity of supply. At the same time the demand for the fuse throughout, at least, the country was somewhat inelastic. This was one of the points made by the defendants in the case of Bickford V Skewes: that one manufactory was sufficient to supply the whole country. The production of fuse would have to wait on the use of explosives as quantities as well as entities.

Success in legal action may to some extent have allowed Bickford, Smith and Davey to enjoy much of the monopoly their patents granted to them for at least a few years. But any part of the market not supplied by the firm was a loss. With a device so intrinsically simple as the safety fuse any sort of technological monopoly would have been impossible to maintain. A momentary examination of a sample would have been enough for very many men to have worked out a way of making the same thing. Attempts to circumvent the patent will be discussed presently.

If within the United Kingdom the firm was largely able to protect its equity, it could not so easily do so overseas, in those countries outside the growing British empire. The only way to secure the firm's interests abroad was to have a resident agent and also perhaps partners who were nationals of the country concerned. The first overseas branch was set up at Amesbury, Connecticut, U.S.A. in 1836. This is worthy of note because it could be taken as an indication of the firm's strength and standing only some five years after its founding. It may well be that, in the case of Bickford, Smith and Davey, where the copying of their product was so easy, they had no choice but to open up branches abroad. It should also be remembered that this was before the passing of the Limited Liability Act of 1855.

The French branch of Bickford's opened in Rouen, in 1839, under the direction of Mr. Simon Davey. The Rouen branch contributed at least one patent - the 'instantaneous fuse' of 1855 - to the firm's

holdings. But apart from that the Rouen branch seems to have taken on a separate existence. In France, Bickford fuse was known as Le Cordon Anglais.

Of the German branch of the firm which was opened in 1844 nothing has been found in the literature reviewed.

Bickford, Smith and Davey enjoyed their trade monopoly for only about fifteen years. After that they were assailed by many attempts at circumvention and infringement. Much of this alternative development came from the firm's home county,

The case of Bickford V Skewes has already been cited. Closer to home, the shareholders and management of the Cornish Mines were presumably unhappy with Bickford's terms of trade because in 1846 they opened the Unity Safety Fuse Company at Little Beside, Scorrier, Cornwall. No information has been found to show how Unity was able to circumvent the Bickford patent. It seems unlikely that they operated under licence. The saving to a large mining syndicate in being able to supply itself with a necessary article is obvious. The loss of a market so close to home must have affected Bickford, Smith and Davey's revenues for some time. But common sense suggests that a mining syndicate of the size of Cornish Mines would have been too formidable in litigation to challenge without danger. The Unity Safety Fuse Company was still in business in 1903.

Again, the Times of 6th August 1855 records that there was a gunpowder explosion at Hawke's Safety Fuse Manufactory at Gwennap. This village is within six miles of Camborne.

The growth of competition of this kind continued. As late as 1871 the firm of William Bennet was set up near to Camborne. By the turn of the century the business employed over two hundred workers - women for the most part - in making a fuse, the raw materials for which differed

not at all from those used at the Bickford factory. Clearly there was room for expansion in the fuse industry of the eighteen seventies - but it was not all to fall to Bickford, Smith and Davey.

The advantages of location which the firm enjoyed were few, and of these there were none which could not have as easily been exploited by the competition as it came into being. As has been seen, the advantages of exclusive production and a ready doorstep-outlet did not last long.

A strong locational advantage lay in there being a willing labour force in the local women. Fuse making lent itself to the use of female labour. Even small additional increments to cash-wages would have been important in a remote area.

The real commercial advantages were, however, inherent in the nature of the product.

The value addedness attached to the manufacture of safety fuse must have been enormous. From raw materials bought by weight a product was made which could be sold by the foot.

The raw materials - hemp, tar, varnish, whiting or China clay, and fine-grained gunpowder - must have been readily and cheaply available as either sea-stores or mining supplies.

Only in securing its supplies of gunpowder did the firm of Bickford, Smith and Davey have to invest directly in a powder mill. It is recorded that* in May of 1859 Mr. Thomas Davey made application to the Cornwall Midsummer Sessions for a licence to erect a gunpowder mill and magazine at a place called West Towan, in the parish of Illogan. It may have been that by 1859 the firm's production needs were great enough to call for the integration of a powder mill into the business. But the article from which the above information was taken indicates that at

* Engineering, May 1859.

least part of the mill was to be used to make a new cellular form of gunpowder. This will be discussed elsewhere.

Bickford, Smith and Davey look to have had a sound selling policy. And in at least one case a professional civil engineer went out of his way to write a testimonial footnote:

The observation:

(a) "It has already been stated that the powder was ignited by means of Bickford's patent fuse; but as this material is never made in lengths exceeding 48 feet (14.6 m), it was found expedient, in order to save waste, to use the whole coil, cutting off at the requisite length when absolutely in the hole, and using the remainder in the same way till the whole was used up,"

gave rise to the following at the foot of the same page: *

(b) "The short and remaining ends, though useful for less depths, were of little value, from difficulty of splicing them together. This operation, though troublesome, was resorted to with success on one occasion whilst waiting for a parcel of fuse. On returning the short ends to Messrs. Bickford, they allowed half the length of the new fuze in exchange."

Such apparently generous practices could well be a sign of very hard competition in the trade. Nevertheless the firm undertook some prodigious orders in its day.

Six hundred thousand yards (548 Km.) were consumed in the blasting operations associated with the cutting of the Manchester Ship Canal. * * At the quoted price of 6/10 of one penny per running foot, this represents sales valued at £4,500 in the money of the time.

The returns of military engineering stores during the Siege of Sevastapol show that during the month of February 1855, 3179 yards (2907 m) remained after the blasting of drainage ditches along the British lines;

* No.725. "The application of Gunpowder as an instrument of engineering operations, exemplified by its use in blasting marl rock in the River Severn," by George Edwards, M.Inst. C.E., 17th June 1845, Vol.IV, p.361, et seq.

** R. and P. B.E.I. 1909.

during March the balance stood at 3069 yards (2806 m.); during April no safety fuse was held; by September the stores had been replenished, the return shows that the expeditionary force was holding a reserve of 685 yards (626 m). It was noted that many of the men serving in the ranks of the Royal Corps of Sappers and Miners were experienced quarrymen.*

(W.H. Russell** reports that the French allies failed in their attempt to blow up Fort St. Nicholas with a spectacularly large charge of gunpowder, 50,000 Kg., because Le Cordon Anglais had proved unreliable. Russell does not say whether it was supplied by the Rouen branch of the firm or from Camborne).

An order for one million yards (914 Km) of a special large diameter, gutta percha covered, deep-sea fuse for the government of the Dutch East Indies is recorded.*** This kind of fuse must have cost somewhat more than the common mining fuse and perhaps represents the scale of the firm's activities at its peak.

The technical development of the safety fuse from its invention up to and beyond 1875 was limited. It was limited to ever more complex variations in the means of covering the fuse, and in the machinery for achieving this end. It was limited to possible variations in the composition used in the core which, so far as can be discovered, continued to be common black gunpowder.

Thirty four years after the granting of the original patent the product is essentially the same.

* Appendix to Journal of the Siege of Sevastapol, Captain Elphinstone R.E., London 1856.

** The War in the Crimea, W.H. Russel, 1856, Routledge.

*** R. and P. E.E.I. 1909.

"1049. J.S. Bickford, Camborne, Cornwall, 'Safety Fuse' -
dated 12th April, 1865:

The fuse employed is the ordinary Bickford's patent fuse, as described in the specification of letters patent dated 6th September 1831, specially prepared so as to prevent fire from bursting through the coating, so that it shall ignite a charge only at the end of it. The means the patentee employs for the accomplishment of this object are as follows:- the fuse is first varnished with the usual tar varnish, then covered with another layer of yarn. It is then passed through a varnish composed of seventeen parts of fine potter's clay, one part of glue, one part of red lead, and one part of alum by weight. The glue and alum are dissolved together in hot water, and then mixed with the clay and lead with sufficient water to form a thin paste. The fuse..."

The specification takes on an incantatory complexity as it proceeds. The names of the different grades of safety fuse themselves trace the developments in coverings:

"Safety fuse ... single tape fuse ... cotton fuse ...
white finished, taped, double countered fuse ... double taped
fuse ... white finished, double countered, gutta percha fuse...
white finished, double countered fuse ... black finished, double
countered fuse ... Jumbo ..." *

The specification for a patent granted to a Mr. James Harbooth Gresham of Hull and dated 26th October 1867 represents a fair specimen of the sort of competition that emerged as the century progressed. The description is not unusually long or involved for a specification of its kind. It does, however, offer as 'peculiar' that which had long been commonplace.

The Britannia Safety Fuze differed from any other only in so far as it incorporated in its core threads of 'fibrous material' that had been soaked in a solution of saltpetre, and the outer casing was in part formed from strips of book-binder's tip-board moulded into semi-circular

* The Engineer, 4. 9.1867.

trough sections. The fuse offered 'a tough homogeneous and impervious casing'.

The records abound with registrations of patents for fuses. Fortunately many are later entered as 'not proceeded with'. Many also merely mark patents filed for the sole purpose of hedging off competition by drawing a distinction where there was only a trivial difference.

This did not go unremarked in the technical press. In commenting on Smith's (Bickford, Smith and Davey) Patent Gutta Percha Safety Fuse in The Practical Mechanic & Engineer's Magazine of 1st June 1867, the editor of the day shows that he was fully alert to the situation and did not hesitate to add his comments to the final paragraphs of an article in which the proposed new fuse is described:

"The schemes are ingenious; but we cannot give Mr. Smith the credit of entire originality of contrivance, seeing that at least two parties have done the same thing before, or at least pointed the way. Mr. Bewley of Dublin, and Mr. Carbines of Cornwall, have both proposed the adaptation of gutta percha for the same purpose. The plan of the former gentlemen indeed expressly describes the method of manufacturing the tubes in terms almost identical with those of Mr. Smith."

(There is at least a hint of very longstanding acrimony between manufacturers. The patentee of a lead covered fuse, Mr. Carbines, above, is described as 'a miner' by one of the grandsons of Mrs. Smith when in 1903 he is contributing to a review of progress in the explosives industry.

Development in the core material was negligible. Oscar Guttman, perhaps the most widely experienced expert in the practical manufacture of explosives then living, wrote, just after the turn of the century:*

*Twenty Years Progress in Explosives (p.5), Oscar Guttman.

"Further progress, although seemingly small, has been that made in powder for safety fuses ... formerly it was not uncommon to use the siftings of mining powder for safety fuses, but the stringent requirements have compelled all manufacturers to make a special quality of fuse powder to constant composition, density, and uniform granulation, in spite of its almost dust-like character ..."

It is interesting to observe that what would have been a new fuse core material was actually suggested by Colonel C.W. Pasley when he was giving evidence in the Bickford V Skewes case. The plaintiffs had been challenged to show that any other material than common gunpowder could be used for the core of a fuse:

"Colonel Pasley ... had no doubt that one substance answering the description, namely detonating powder, might be used ..."

Again, Colonel Pasley looks to have suffered from a technological blindspot. (Or perhaps he was answering in cross-examination with the only possible answer, for fulminate of mercury was the only other explosive then in practical use). The cause of the blindspot in this case, however, may not have lain in his not being able to visualise the manufacture of such a fuse as his not being able to imagine an application for it. The patenting of just such a fuse as Pasley suggested had to wait until the end of the century when an Austrian, Colonel Phillip Hesse, patented an invention which detonated at 5,000 metres per second.

CHAPTER 4

POTASSIUM CHLORATE EXPLOSIVES

(1857 - 1875)

Claude L. Berthollet (1748 - 1822) is credited with the discovery of a means of producing potassium chlorate on a scale and of a purity which allowed its use in explosives. Glauber (1603 - 1668) is thought to have prepared potassium chlorate, but the extent of his work with the compound is uncertain.

A logical step to take upon the discovery of a new and powerful oxidising agent was to experiment with its possible substitution for saltpetre in gunpowder. Count Berthollet attempted this in 1788. The attempt was met with almost immediate disaster. Marshall* gives a useful short account of the event:

"A party had been made up to see the first of the new powder made up in the mills: M. and Mme. Lavoisier, M. Berthollet, the Commissary, M. de Chevrard and his daughter, the engineer, M. Lefort, and others. Whilst the mixture was being incorporated in a stamp mill, the party went to breakfast. Lefort and Mlle. de Chevrard were the first to return, and as they did so the charge exploded with great violence, throwing them a great distance and causing such injuries that they both died in a few minutes."

This set-back to any potential large development of chlorate based explosives was to be permanent. There was no later rehabilitation of potassium chlorate compounds as there was to be with first gun-cotton and later with nitroglycerin.

But so efficient an oxidising agent was to be perennially attractive to inventors and amateur chemists. And it is for this reason that a note of firm reservation must be made. The record of the efforts of inventors working with chlorate explosives is taken for much the most part from details of patents granted during the period. A patent granted - and thus

*Marshall A: 'Explosives', Churchill, London 1917.

by implication an 'inventor' created - did not, however, necessarily advance the technology of explosives in any material way. The chlorate explosives, particularly, look to have attracted the endeavours of the empirical and foolhardy dabblers. The attraction was that little capital or plant was required and it was seen that there was likely to be a rich reward waiting for the man who could find a way to render potassium chlorate explosives tractable.

At the more general level, however, Government and the established manufacturers of explosives, throughout the century, shunned almost all compositions containing chlorate of potassium for any use as main-charge explosives. Sir Alfred Abel, for many years the principal adviser to the government on matters relating to explosives, was in no doubt about the limitation to the use of chlorate explosives in mining:

"Some of the preparations of this class, which, disguised by fancy names, occasionally find their way into miners' hands, are of so dangerous a character that it amounts to little short of a criminality to endeavour to find a sale for such mixtures."

On Recent Investigations and Applications
of Explosive Agents, by F.A. Abel, Chemical
News, 15th September 1871 (p.126)

(Recognition that the dangers associated with chlorate explosives was not outweighed by the advantages they offered was not confined to the United Kingdom. The following quotation comes from an American work. It is included because it illustrates the probable 'fringe' nature of chlorate products when it came to their sale to the Public.

"Many are deluded as to its safety by so-called experiments with freshly made powder. Manufacturers of the compounds may attempt to show its safety by cutting and hammering it, and similar tests; but let the powder be exposed to the natural atmospheric action, attract some moisture during the damp foggy night, and then get dry, and the least friction or blow will cause an unexpected explosion...)"

The Modern High Explosives by Manual Eissler,
John Wiley & Sons, New York, 1884.

Nevertheless, chlorate explosives were made and and used, though perhaps none very extensively, during the period under study. For this reason it is thought appropriate to bring together the few details which it has been possible to locate, and to present them. But the very diffuse nature of the data dictates that the most profitable way of doing this will be to offer, as examples, details of those few chlorate explosives for which more than a very little information is available. For the rest, these will be classified according to the date of their patent registration and collected together, along with any fragmentary material, in an appendix (Appendix I). Though it will be seen that some of the headings in the appendix are more lengthy and detailed than some of those used in the main text of this dissertation, those chosen for use in the main text are considered to be more generally representative of their class than others which, although there is more, and often more interesting, detail available, are more in the nature of asides to the main narrative of technical development.

The progression of development for the chlorate explosives clusters around three separate approaches to finding a way to use them. These are seen as having been - chronologically - the substitution of potassium chlorate for potassium nitrate in the traditional gunpowder; the so-called 'white' gunpowders; and, those powders in which it was attempted to modify the violence which resulted from the inclusion of potassium chlorate in the formula.

Chlorate Gunpowders

Only one British patent for a compound that can properly be cited as an instance of a potassium chlorate gunpowder, similar in all respects to a conventional black gunpowder save that the potassium chlorate was substituted for the potassium nitrate, *will be discussed.*

Kohler's Powder, British patent No.1622, of 10th June 1857 had, according to Cundill, the following formula:

"Chlorate of potash, 70 parts; sulphur, 20 parts; charcoal, 10 parts."

Cundill appends the single terse comment:

"Obviously a dangerously sensitive powder."

As a probable registration exercise to secure a continental patent, it is possible - probable - that this powder was never actually produced in the United Kingdom.

Bellfort's Powder, British Patent No.2,910 of 10th April 1857 was rather a use of potassium chlorate with a black gunpowder than in a black gunpowder. Ordinary large grain gunpowder was treated with a saturated aqueous solution of potassium chlorate, and dried. Like the dusting of mealed black powder which was used on some varieties of barytic gunpowder a few years later (1867), the pelicle of chlorate would have been seen to have enhanced the supply of oxygen available to the gunpowder when it was fired. It can be supposed that the very low solubility of the potassium chlorate would have allowed the coating of crystals to be applied with the use of so little water that the gunpowder grains would not have been much dissolved.

The lesson of 1788 was well learned. Whatever else was done in attempts to make use of mixtures containing chlorate, the extreme danger which attended any attempts to make pressed, granulated, powders was fully recognised.

White Gunpowders

For the purposes of this study those combinations of potassium chlorate with potassium ferrocyanide, or with antimony sulphate, or with any other metallic salt, will be classified as 'white' gunpowders. This

classification is an arbitrary one made to group together a few explosive substances which it is thought were devised to produce the most violent and sudden reactions possible.

(Such powders were of course not entirely 'white' at all. Mixtures containing any significant proportion of potassium ferrocyanide would have yielded a powder that was somewhat yellow; antimony sulphide would have given rise to a light grey powder; the red orpiment (trisulphate of arsenic) used in Melville's Powder would have inclined that compound towards a shade of pink).

An account of a white gunpowder was first published in the United Kingdom in the journal Chemical Gazette for May 1850. The paper, On a new kind of Gunpowder, by M. Augendre was reprinted from Comptes Rendus XXX (p.179).

In the light of what was later to be known about the extremely capricious nature of such compositions there is a matter of fact quality to the tone of the paper which is hair-raising.

Augendre gives his formula:

"Powdered, crystallised, prussiate of potash, 1 part; white sugar, 1 part; chlorate of potash, two parts."

Such formulae under the names of 'German gunpowder' and 'American gunpowder' are numerous in the journals; a good sample will be given in an appendix.

The mixing of small quantities at least was carried out in brisk fashion using dry ingredients:

"... they (the ingredients) may be pounded together in an agate mortar. Not the least fear need be entertained of the most powerful friction..."

Larger quantities were first made moist with water. Augendre's description of what he saw to be the advantages and the disadvantages of his powder indicate that he had undertaken some experimental work

before he proceeded to publication:

"It is formed of substances whose composition is well determined and fixed, and can therefore always be obtained of the same strength by weighing off the constituents. It leaves less fouling than gunpowder. These substances are unalterable by the action of moist or dry air, so they can be kept any time ... The manufacture requires less time, a fortress might ... be provided with the several constituents in powder ... the force is much greater ... Lastly, it has the advantage that the dust has the same effect as the grain, so that each constituent might be reduced to a very fine powder separately by ventilation,* and the several powders then mixed in a rotating leather barrel.

The new powder has the following disadvantages: - it oxidizes the iron barrels very much, so that its use is limited to bronze barrels, and for filling projectiles. It is more easily inflamed than ordinary gunpowder, but not so readily as other mixtures with chlorate of potash."

The inventor did have an accident with his new gunpowder at one point, and advertised the fact fully in his paper. His description gives the conditions under which the accident occurred - it also suggests the simple misconception he held as to the nature of the powder he was working with.

"The author directs attention to the circumstances readily conceivable from the behaviour of the chlorate of potash towards several other substances, that the greatest care should be taken to avoid introducing into the mixture any charcoal or sulphur, or mixing any ordinary gunpowder with this powder. The author describes an accident which occurred to him from this cause. He titurated some powder which had been kept in a powder flask, and had become mixed with a few granules of ordinary gunpowder; a further quantity of the prussiate of potash was added to it, so that the whole amounted to more than 50 grams; on the second or third turn of the pestle the whole mass exploded ... the author lost eyebrows and eyelashes, and remained for two days uncertain whether he should lose his sight..."

*('ventilation' probably refers to a process akin to winnowing; the lighter and thus finer particles drift furthest when allowed to fall through the air freely).

Augendre's quite understandable preoccupation with the effects of a slight contamination of common gunpowder seems to have driven out of his mind the consideration that the mixture he was working with was intrinsically dangerously sensitive. The warning Augendre's account gave should have been clear to any prudent person, but if the number of patents concerned with one form or another of white gunpowder is an indication it did not. It may be that experimenters with white gunpowder were statistically more fortunate than they might have been.

(It is observed that for many years (1844-1875) that relatively large quantities of a composition very similar to a white gunpowder must have been made in the German states. The cartridge for the Dreyse needlegun was primed with a chlorate, antimony sulphide, etc. composition).

Horsley's Powder

A third class of chlorate explosives can be formed of those explosives in which the potassium chlorate stands in the same relation to the other constituents as that served by the nitrates in the modified gunpowders. Horsley's Powder is the most representative of these powders. Of all the other powders of its class, Horsley's powder is the only one for which it has been possible to find a firm record of its practical use. It was applied to the blasting of a railway cutting at Millford, 'without accident, and with success'. An offer of the powder to the government was rejected; it was tested for its suitability as a filling for torpedoes by a Captain Harvey.

The patent for the explosive was taken out by the inventor himself on the 19th April 1869. But Horsley claimed that he had delayed taking out a patent for his discovery for almost seven years. The Journal Chemical News for 16th August 1862, (p.87) carries a paragraph in which this assertion is made. The paragraph, On an Explosive Compound by

John Horsley F.C.S. (Fellow of the Chemical Society), gives a description which is much the same as that published in much later material.

(Horsley recommends the mixing of gunpowder with powdered galls, but makes no actual mention of his using chlorate; though this may be no more than a certain unhandiness in his prose). The paragraph ends: "I have been acquainted with this for several years, but never published it before."

(The reason for this retrospection may be attributed to the fact that at some time Horsley was in dispute with an inventor called Ehrhardt. It is not known if the dispute was taken before the courts; if it was, and some record of the proceedings could be found, much might be revealed of the background to a relatively obscure part of the development of explosives).

Horsley's Powder was composed of three parts of finely powdered potassium chlorate to one part of powdered 'gall nuts'.

The most detailed account of the process of making Horsley's powder found was that which was printed in the journal, The Engineer, of 12th March 1869, in the article On Explosive Compounds for Engineering Purposes by Mr. Perry Nursey.

An overview of the method described by Nursey shows immediately the limitations and dangers attached to any large scale production:

"Mr. Horsley prepares this powder by grinding of the two ingredients carefully (apart) and intimately ... mixing them in a wooden mortar with a pestle of the same material, as this is less liable to be exploded by a blow. An alternative method of mixing, also adopted by Mr. Ehrhardt, appears the safer where large quantities are required.

This consists in passing the ingredients through a series of horsehair sieves arranged one below the other and having a rocking motion imparted to them. Upon the upper sieves the ingredients are first mixed by being run together from two

receptacles placed above the arrangement and containing a given weight of chlorate of potassium and the other one third of such weight of (powdered gall nuts). The chlorate being much heavier than the gall nuts, their respective volumes are about equal. Motion being imparted to the sieves, and as the two finely ground ingredients pass downward through the sieves, they become blended, and form the explosive compound."

The Power of Chlorate Explosives

The power of chlorate explosives is something which will warrant a little discussion. Were they high explosives in the same sense that nitroglycerin is? Were they low explosives? Did they come somewhere in between? Did whether they were high or low depend upon the nature of the compounds the pure potassium chlorate was mixed with. It is entirely possible that since chlorate explosives have been generally out of use for almost a century that there has never been an occasion when one of the more violently explosive chlorate compositions has been the subject of scientific testing.

What can be offered is an account from the article by Mr. Perry Nursey cited above which describes a test he witnessed which was designed to compare the relative force of Horsley's powder with that of the best quality sporting gunpowder. The description is of the effect of fifty grain (15 grams) charges fired off in the chamber of an eprouvette one inch (2.54 cm.) from a stout block of elmwood:

"The disruptive force of Horsley's powder on the wood was as if a solid body had been driven into it, separating the fibres and tearing a hole completely into it. The force of the small grain gunpowder merely left a mark upon the surface of the wood blocks..."

Horsley's powder would seem to have displayed something of the qualities of a high explosive.

The Use of Tannin Materials in Explosives

The first record found which mentions tannin materials as constituents of explosives appeared in the Practical Mechanics' Journal for 1st June 1861, (p.77).

"Blasting Powder - A patent has been taken out in Belgium for the manufacture of blasting powder from spent tan bark... for the effect of the powder is said to be very great ... and the conversion of the spent tan-bark would confer a great boon on the leather trade..."

(It can be conjectured that this paragraph may have been the cause of John Horsley announcing his work on his chlorate explosive).

There would seem to be no particular property inherent in the various tannin materials used which could be said, from the point of view of the chemical reaction produced, which would commend it rather than, say, charcoal, or, wood flour, or any of the other cellulose fibre materials which were tried. Sir Frederick (then Professor) Abel, speaking in the discussion which followed the reading of his paper^{*} on explosive agents to the Institution of Civil Engineers in 1873 is quoted in the printed minutes as saying:

"He really failed to discern the existence of any merit in spent tan and sawdust as constituents of a blasting powder."

Nevertheless, at least ten of the compositions mentioned in Cundill's dictionary - nitrate, chlorate, and nitroglycerin explosives - contained either spent tan or powdered galls; others contained broadly similar materials, everything from sea-grass to coffee grounds.

Spent tan bark is likely to have been a very plentiful waste material in the middle part of the last century. It can sensibly be suggested that it was cheap and that because it had been undergoing a process of soaking for as much as nine months it would probably have been easily

* Paper No. 1342.

broken up and ground into a uniform mass of small fibres.

Oak galls were readily available because they were also used as a particularly rich source of tannic acid (60%). But they would have been no cheap substitute for charcoal, since they were ordinarily imported from the Levant. It may be that Horsley specified this material simply in order to confound Ehrhardt in their dispute. Only Horsley specifies the use of 'gall-nuts'.

The latest reference to Horsley's powder occurs in an article in the journal Engineering for 29th September 1871; Explosive Compounds (various explosives). Engineering is a little guarded in the expression of its views:

"Horsley considers his compound a safe one, and that may be so in his or other equally careful hands, but beyond this we are by no means prepared to endorse his opinion."

CHAPTER 5

GUN-COTTON

(1845 - 1875)

Schönbein's Discovery

Christian Friedrich Schönbein is generally credited with the discovery of the explosive gun-cotton. There is not, however, a single date which can be cited for the discovery. The earliest general period which can be given is taken from a statement made by Schönbein himself in a paper published in the Philosophical Magazine for May of 1847 (p.7): "All this passed in December 1845, and the first few months in 1846." A scholar who had access to Schönbein's original letters was equally unable to give even a close approximation:

"I do feel quite sure whether there was not another letter of Schönbein's which is now lost, coming between those of March 5th and June 20th (of 1846). His expression in the letter of June 20th seems to me to indicate this:

'It will perhaps interest you to know that I have not made many experiments with my gun-cotton.'

This is alone enough to show that the writer assumes on the part of Berzelius an accurate acquaintance with the then state of affairs; and this would be simply and easily explained from the correspondence which they were usually so fond of keeping up. Though according to Schönbein's own account in the Allgemeine Zeitung of 25th October 1846, the first experiments on big guns on a large scale had been performed in the weeks of April 6 - 12, and the discovery had attracted the attention of the general public to a very unusual degree..."

The Letters of Jons Jakob Berzelius and
Christian Friedrich Schönbein, 1836 - 1847

Edited by George W.A. Kahlbaum

Translated into English by

Francis V. Darbishire Ph.d. and N.V. Sidgwick

Pub. William & Norgate,

London 1900, p.85.

The work which led to the discovery was Schönbein's researches into the sizing or 'parchmentising' of ordinary paper by treating it

with nitric and sulphuric acids. This, whether the paper was made from either linen rags or wood pulp, would have resulted in a substance which was highly inflammable and potentially explosive. Schönbein continued to work on such papers after March of 1846.

Schönbein was invited to demonstrate his gun-cotton at the arsenal at Ludwigsburg, and later at Stuttgart, this time before the King of Bavaria, during April of 1846, and Schönbein continued his experiments at Wurtemberg during that summer.

On 28th July 1846 Schönbein was 'the person who fired the first cannon loaded with gun-cotton and shot'. He had also used gun-cotton to blast a railway tunnel at Istem in the Grand Duchy of Baden. But from the beginning the primary interest appears to have been the military propellant uses of gun-cotton - it was schieswol and schiesbaumwol, 'shooting-wool' and 'shooting-cotton' from the first.

Schönbein's short announcement of his discovery, without revealing the actual method of preparation, was published in Poggendorff's Annalen for May of 1846 and it quickly attracted claims from other German-speaking chemists that they too had independently and more or less simultaneously discovered explosive nitrocellulose compounds.

Rudolf Christian Böttger, who was professor of chemistry at Frankfort, claimed an independent discovery. For some reason Schönbein appears to have acquiesced over Böttger's claim. It may be that Schönbein was under some pressure not to be seen to quarrel with a fellow German. Nevertheless, he uses an icy precision in stating who had discovered what, and when, in his paper which was read before the Philosophical Society and published in the Philosophical Magazine for May of 1847 (p.7): On the Discovery of Gun-cotton:

"Our two names thus became associated in the discovery of the substance in question..."

And:

"To Böttger, gun-cotton must have been particularly interesting as he had previously discovered an organic acid which deflagrated readily..."

And even more pointedly:

"I prepared gun-cotton and applied it to the discharge of firearms, and that Böttger did the same in August."

A rather more determined competitor, and one who, his declarations notwithstanding, had commercial aims, arose in the person of Doctor Friedrich Julius Otto, who was professor of technical chemistry at the Collegium Carolinum at Brunswick. Otto announced his work in the 'Hanoverian Gazette' of 5th October 1846, from which it was published in the Times:**

"Entirely independent of Schönbein and Böttger, but relying on an observation of Pelouze, I have succeeded in producing an exploding cotton ... In order to bring the results of important discoveries to the highest state of perfection ... in order that many persons may turn their attention to the subject. I scorn therefore to sell or take out a patent for my very interesting discovery***, ... and I now publish it for the general good of the public."

Otto's method of preparation required that the cotton be dipped 'for half a minute into highly concentrated nitric acid (the acid which I use being made by the distillation of 10 parts of dried saltpetre and 6 of oil of vitriol)'. The material thus produced had to be carefully washed, and because the cotton had felted together it had to be picked free of 'knotty particles'.

* In August of 1846 - fully six months after Schönbein.

** Reprinted in Chemical Gazette for 17.10.46, p.430.

*** The first asterisk refers to an editorial comment: "If the very interesting discovery had not been made long before, would Dr. Otto have been the first to make it?"

In England, Thomas Taylor, who was Schönbein's friend and correspondent in the country, remarked in a letter which was published in the Chemical Gazette for 17th October 1846 (p.431) that:

"The process I have recommended is of course only a modification of Dr. Otto's; it has the advantage, however, of being much cheaper and more easily managed. The strong acid used by* him is not only very expensive but is rarely to be met with, while sulphuric acid and common nitric acid are very cheap and may be procured anywhere..."

Schönbein himself viewed Otto's claims with some apprehension.

In October of 1846 he wrote from Stanmore, in England, to his wife:

"According to the opinion of experts the patent is not in danger through Otto's articles. The English Press is unanimous in criticising all later discoveries, and saying that it is discreditable to the men to deprive me of my well-earned deserts."

The Letters of Jons Jakob Berzelius to Christian Friedrich Schönbein, 1836 - 1847. Edited by George W.A. Kahlbaum (Basle), Tr. Francis V. Darbishire Ph.d. and N.V. Sidgwick, Pub. Williams and Norgate, London, 1900.

(Part of a footnote: p.89)

(The names of K. Karmash and F. Heeren, both of Hanover, and J.A. Knop of Leipzig, appear in the literature but no precise details of these mens' work with gun-cotton can be offered).

The French reaction to the discovery of gun-cotton can be given most succintly by quoting what the editor of The Practical Mechanic and Engineer's Magazine for May of 1847 (p.180) had to say:

"Up to this time there had been little or no attention paid to the matter on the part of the French chemists, and it seems that the experiments of Mr. Groves at Southampton, at the meeting of the British Association, first drew the notice of the French to this substance. It was at first deemed an incredible

* Fuming nitric acid.

matter among the Parisians, and gave rise to some humorous observations, but when there could no longer be any doubt upon that head, and the chemists of other countries had made known their processes for preparing the cotton, they then took a lively interest in the thing all at once, and they pretended to find in the explosive an old French discovery. It is nothing more, they said, than Xylodine which Braconnet found out, and which Pelouze experimented with; still they gave Schoenbein the merit of putting the substance into the barrel of a musket...

It would have been otherwise easy to see that there was an essential difference between xylodine and gun-cotton - nevertheless the error survived through some months.

In the early part of November last (1846) Mr. Walter Crum, of Glasgow, published a memoir in which he showed that gun-cotton is not the same product as xylodine ...*

The first year after Schönbein's discovery of gun-cotton was a scramble. The missing piece which Schönbein had supplied was the use of a mixture of sulphuric with nitric acid, instead of nitric acid alone. That given, there was little left for other chemists to do.

Gun-cotton was a German discovery. Most of the chemists who had to do with first years or so of its introduction were Germans. It is, therefore, not surprising that the history of gun-cotton should be very much more thoroughly documented in German language sources than it could be in the few contemporary English ones which can be found. The work most frequently mentioned in English texts as a comprehensive account of what occurred between 1845 and 1847, and beyond, is Romocki's Geschichte der Explosivstoffe 1896, ii, 107 f.

Gun-cotton in the United Kingdom

The First Phase (1846 - 1847)

To attempt to find support for a new invention in England, or at least to gain the wide-reaching protection afforded by British patent

laws, was an obvious and urgent need for Schönbein. He had already sent samples of his gun-cotton to his correspondents, Farady, Herschel, and Grove, in March of 1846.

(It can be wondered which of these three - if Schönbein himself was not - was responsible for coining the English term gun-cotton, as a proper translation of Schiesswol).

It was not, however, until August of 1846 that Schönbein was able to come to England himself. With the help of Groves it was arranged to get Government sponsorship for a demonstration of gun-cotton's military uses at both Woolwich and Portsmouth. Gun-cotton was also discussed and demonstrated at that year's meeting of the British Association at Southampton.

The British rights in gun-cotton were secured by the taking out of British Patent No.11407 which was granted from 8th October 1846. The patent was entitled, "Improvements in the Manufacture of Explosive Compounds." It had the additional sub-title: "communicated to me by a certain foreigner residing abroad, John Taylor of Adelphi, Middlesex."

The sub-title was, it can be supposed, necessary to give a legal hand-hold should John Taylor's integrity not have been all it should be. For whatever reason, it looks to have been thought prudent to register gun-cotton in at least the name of a prominent British national. Of all the acquaintances Schönbein had in this country, John Taylor was the one who was not only a considerable scientist but also a successful entrepreneur.*

The specification for the patent gave detailed directions for making gun-cotton; but, so far as can be seen, it did not offer any instructions for manufacturing it on a large scale:

* See John Taylor by R. Burt, Pub. Moreland Press, London 1977.
ISBN. 0 - 903 485 362.

"The invention consists of a manufacture of an explosive compound applicable to mining purposes, the throwing of projectiles, or otherwise as a substitute for gunpowder ... best suited for the purpose of the invention is cotton, in the same state in which it comes into this country, but cleansed of any extraneous matter ... The acids I employ are nitric acid of from 1.45 to 1.5 sp.gr. and sulphuric acid of 1.85 sp.gr... mix them in the proportions of one measure of nitric acid with three measures of the sulphuric, in a convenient vessel of earthenware ... great heat will be produced. The mixture should be allowed to cool until a temperature of 50° to 60°F (10°C - 15.5°C) is reached. The cotton should then be immersed in the acids ... the acids are then to be pressed or drawn off ... is next to be covered and left to stand for about an hour..."

(Other washing, pressings, and a final drying are prescribed).

"It should next be immersed and well stirred in a weak solution of potassium nitrate, 1 oz. to 1 gall. (1: 160 cc). The use of this solution appears to add strength to the compound ... it is not essential and may be dispensed with ..."

(Further washings and pressings, and a final stoving)

"... I do not restrict the invention to the use of cotton..."

Blasting with gun-cotton was first tried out in this country in Cornwall. Although Schonbein was present, the business looks to have been arranged by John Taylor.

"The first place where it was tried was in a granite quarry at Spargo, near Penryn, where the Professor (Schonbein) and himself (John Taylor) were accompanied by ... and several other gentlemen besides Mr. Hoskins the owner of the quarry, and some other people of that class. The surprise and incredulity of the workmen on that occasion were very great. When he (John Taylor) charged a hole with cotton, they thought he was doing a very absurd thing, and one of them offered to sit on the hole for a pint of beer. Two holes were selected by the quarrymen, of which he had the choice of one, which he charged with a proper quantity of gunpowder. The other hole was then charged with a quarter part of that weight of cotton.

The hole charged with powder was fired and produced its effects completely. The other hole was then fired, and to the astonishment of the workmen, tore the rock into a number of fragments. It did more than required, the charge being altogether too great ..."

Chemical Gazette
17th October 1847, p.430.

Other trials were carried out near Penryn to demonstrate the relatively smokeless qualities of gun-cotton.

The right to manufacture gun-cotton was leased to the firm of Messrs. John Hall & Sons of Faversham. For a thousand pounds sterling down payment and a promise of a third of the profits to Schönbein, Hall & Sons became the sole United Kingdom manufacturers. The commercial potential offered by gun-cotton must have struck the Halls as virtually limitless. The firm was already well established in the black gunpowder trade. This meant that the organisation for distributing gun-cotton was already established and, above all, the most likely customers were known. There is a sense in which the firm would have been in competition with itself for its own markets; but then it would also have been in competition even more sharply with other makers of gunpowder, and in 1846 these were numerous.

The simple nature of the process must have made it an easy target for infringement. Messrs. Hall & Sons may well have needed to declare their determination to fight any encroachment:

"Persons detected in making, using, or vending any imitation of the patent article, will be proceeded against on all occasions. John Hall & Sons, Patentees of Professor Schönbein's Guncotton for England, Scotland, Ireland and the British Colonies."

Advertisement in the English Mechanic
for November 1846

No information at all can be offered to show anything of how Messrs. Hall and Sons went about putting Schönbein's gun-cotton into

commercial production. Setting up a gun-cotton factory must have required only a fraction of the investment needed to set up a gun-powder mill: there was virtually no machinery needed. The making of gun-cotton required only that the hanks of cotton be dipped in the mixed acids and then thoroughly washed and dried carefully several times. The main outlay would probably have been for acid-proof vats of some kind, and for stoves which were safe to use. The work looks to have been labour intensive. The firm appears to have got into production very quickly indeed by modern standards.

By October of 1846 the price of gun-cotton had attracted an adverse comparison in the Press:

"With regard to the cost of gun-cotton, a correspondent of the Mining Journal says -

The price of gunpowder over the whole of England, ranges at 40s. per barrel, of 100 lbs. (45.4 Kg.) or 4 $\frac{3}{4}$ d per pound. The lowest price of cotton at Liverpool price current is Surat - the price of which is 6 $\frac{1}{2}$ d per lb. Cost of manufacturing, I calculate,

Nitric Acid at 1s. per lb.

Sulphuric Acid at 2d. per lb.

Cotton takes up and holds, when saturated after pressure, its own weight of water; therefore, 1 lb. of cotton will hold - 1.000 nitric acid, .6158 sulphuric acid = 1.6185 = 1s.1 $\frac{1}{4}$ d = 0.6 $\frac{1}{2}$ d cotton + 0.6 $\frac{1}{4}$ d = say, nearly 30%, in labour, loss, and charges = 2s.2d. per lb. for gun-cotton ..."

Mining Journal, October 1846

Reprinted: Practical Mechanic and

Engineer's Magazine

December 1846, p.19

The same article questions the advantages offered by gun-cotton over gunpowder (and unsuspectingly hints at the cause of the disaster to come):

"The estimated effect is said to be twice that, by weight, of gunpowder - say, therefore, 1s.1d to do the work of powder. How can, therefore, gun-cotton compete with powder, at 4 $\frac{3}{4}$ d per lb.? Again, $\frac{1}{4}$ lb. occupies about 8 cubic inches. In my experiments I find at a temperature of 130⁰, the gun-cotton explodes spontaneously - this I discovered in the process of drying it..."

Adverse publicity or none, the sales promotion of gun-cotton was forthright and without pretention. The makers had also anticipated a probable objection by the users and taken care to make up the explosive into a comprehensive array of charge-sizes:

"To mine and colliery proprietors, slate quarry owners, railway contractors, ironmongers, dealers in gunpowder, and others.

Messrs. John Hall & Son,* the patentees and sole manufacturers of Schönbein's patent gun-cotton, respectfully state that they are now prepared to supply the patent gun-cotton (compressed for convenience of carriage), in round and square paper cases of four ounces (113 grams) each packed in boxes containing 50 and 100 cases each, at the price of three shillings per pound, for ready money. And also in tubes or cartridges of 1, 1.1/8th, 1 $\frac{1}{4}$, 1 $\frac{1}{2}$, inches (2.54 cm., 3 cm., 3.2 cm., 4 cm.) in diameter, containing 2, 4, 6 and 8 ounces (56 grams, 112 grams, 168 grams, 336 grams) each, at an additional charge of 1, 1 $\frac{1}{2}$, 2, and 2 $\frac{1}{2}$ pence, each tube or cartridge. For blasting in slate quarries, paper tubes will be supplied three feet in length, containing one ounce (28 grams) of the patent guncotton per foot. Four ounces (112 grams) of guncotton are equal in power to 24 ounces (672 grams) of blasting gunpowder ..."

Historical Papers on Modern Explosives

by George W. Macdonald, M.Sc. (Melb.)
Pub., Whittaker & Co., London, 1912, p.53.

As it stood, gun-cotton was too powerful, too shattering in its

* Sometimes Messrs. Hall & Son; sometimes Messrs. Hall & Sons.
This may of course show a real increase in the family.

effect, for bringing down materials such as slate which had to be used in large pieces. What was being offered in the paper tubes was gun-cotton teased out to occupy a large volume. This technique was later used by artillerists to reduce the stress of gun-cotton on the barrels of their guns. The use of tubes was in any case absolutely necessary to prevent the long fibres of the early form of gun-cotton from 'binding' on the jagged edges of shot-holes. This disadvantage in gun-cotton has to be set against the advantage - often cited - that it could not be carelessly spilled about as gunpowder often was.

An entirely new form of explosive called for very specific instructions for its use. Messrs. Hall and Son gave the buyer and user of their gun-cotton blasting charges clear and detailed directions. There was, however, little which was new to men used to blasting with gunpowder:

"It is recommended that safety fuse be used, and inserted into the cartridge to the extent of about two inches (5 cm.), and tied fast to the neck of the cartridge with a piece of string. There is a black dot at one end of the cartridge to show where the fuse is to be inserted.

The hole to be tamped should be made sufficiently large in diameter, that the cartridge may reach the bottom without there being any occasion to force the same down. The hole should be made as dry as possible before the cartridge is inserted. When the cartridge is down to the bottom of the hole, put into the hole a handful of dry sand or clay, so as to cover the top of the cartridge to a depth of about one or two inches (2.54 cm = 5 cm.), then proceed to ram or stem down, precisely as in the case of blasting with gunpowder, the fuse being cut ... Where there is an absolute necessity for using gun-cotton in a loose state, a wooden rammer only should be used ..."

Historical Papers on Modern Explosives
by George W. Macdonald M.Sc. (Melb.):
Pub. Whittaker and Co., London, 1912, p.52-53.

The immediate conclusion which the above description forces is that the use of gun-cotton in blasting without the aid of mercury fulminate blasting caps required very much more care to be taken in the placing and igniting of the charge. Misfires must have been frequent. It can be imagined that gun-cotton may not have been as reliable as gunpowder in this respect.

On the 14th July 1847 the Faversham gun-cotton factory of Messrs. John Hall & Sons blew up, with a loss of twenty-one lives. The plant was wrecked entirely.

John Hall wrote to Schönbein a few weeks later outlining the situation. The human tragedy is well documented in contemporary newspapers, so it will not be treated here; but the technical and commercial implications which John Hall outlines, after giving his own account of the accident, is revealing.

"We believe that arrangements that have been matured after many months of painful and hazardous personal attention, on the part of our Mr. William Hall, worked out by practical and growing experience acquired by incessant application, for it must be remembered that any small essays of illustrating the mode of preparing, stoving and packing were perfectly futile, when applied to the production of the article in large quantities, where the control of temperature and the difficulty the men have in sustaining respiration with the drying and packing are brought into (without special directions for large operations), are matters to which we must say we are indebted to our own experience and are all contingencies we have worked out, and what we believe no house but ourselves would have had the courage to encounter, but which have been thwarted with the destruction of life and property distressing to contemplate ..."

Letter from John Hall to Professor Schönbein,
London, 23 Lombard St., August 1847.
(From letters in the possession of Mr. C.L.
Watson-Smith of Faversham). Reprinted in
Historical Papers in Modern Explosives by
George W. Macdonald M.Sc. (Melb.), Pub.
Whittaker and Co., London 1912, p.49.

The cause of the accident is now beyond any proof, but John Hall gives the broad attendant and contributing circumstances himself. With a patent which was legally strong but which was also technologically extremely vulnerable there had been every pressure to get into production as quickly as possible. Halls rushed into production before gun-cotton had even been properly analysed. No-one connected with the explosive could have had any experience at all of the explosive outside of the laboratory. The men who were actually steeping raw cotton into mixed acids are unlikely to have had even that. Gun-cotton making must have appeared to be a much safer operation than the manufacture of gunpowder. At the inquest Halls pleaded that safety measures were ordered - it is an irony that these precautions, even had they been carried out, were those appropriate to a gunpowder factory.

Some idea of the sort of work regimen operating at Hall's factory in 1847 can be gained from a short passage taken from an article reporting upon the Coroner's enquiry into the Faversham explosion:

"A sad fatality attended one boy; the lads are employed alternatively in out and indoor work, and this boy was that morning placed to scare birds from a piece of wheat; but the overseer had caught him asleep a few minutes before the accident, sent him to the stove, and thus he fell victim to his drowsiness."

The Practical Mechanic and Engineers
Magazine, September 1847, (p.267).

That the employment of youngsters in any dangerous process is foolhardy goes without saying - though it was entirely usual in 1847. The reason for the alternative employment is found in John Hall's letter to Schönbein, cited above: 'the difficulty the men have in sustaining respiration in the drying and packing.' A youngster was, even then, not expected to endure more than five or six hours of the humidity and temperature around 'the stove'.

Two related causes can be suggested for the Faversham explosion. The first is the simple one. Tired, heat-exhausted, men become almost unwittingly careless, and sometimes even perversely careless. Someone allowed a hank or a part of a hank, a knotted piece, to retain enough acid to cause decomposition. The second possible cause is that the initiation of the explosion was a fire which was spontaneous. In the presence of droplets of the nitrating acid in the air, and also of air-borne cotton fibres, the factory may have been well dusted with impure nitro-cellulose.

John Hall continues his letter to Schönbein, coming inevitably to the financial implications of the explosion. No advanced technology can develop far without business confidence behind it. Schönbein was being reminded that he was a partner in the enterprise and had certain definite personal liabilities himself.

"This calamity ... has exceedingly embarrassed our position and has placed us in the situation of submitting to you the first moment we could get in the accounts, a balance sheet showing the loss and the divisible third, which we place to your debit, in this painful matter ... you will ... recognise what is the feeling of scientific men regarding the manufacture of the article on a large scale. We had made preparations and provided machinery to produce the article in large quantities, but all scientific men agree that its principles are not even yet understood, no party can produce it without all these contingencies ... the most determined opposition of public feeling, prevented us getting it about the country, utterly precluding any possibility of our concentrating any quantity in any magazines ..."

The Faversham explosion gave rise to a serious legal and transport problem. Since the Faversham factory had been in operation for about nine months, it can be assumed that there were quantities of explosive in transit and in store all over the country. Suddenly gun-cotton had

become highly suspect. Not even in those apparently callous days could anyone be forced to handle something which might have meant certain death the next instant. Nor could any Railway Company be asked to endanger its rolling stock and its employees by returning the gun-cotton to the makers. Gun-cotton stocks could neither be left where they were nor returned to Faversham. And since the goods were not as advertised there would be likely to have been many demands for a refund of purchase price.

How Messrs. Hall and Sons overcame these problems is not known. Some boxes of gun-cotton at least, from the stocks held at the Faversham site, were buried in the ground and stayed there for some sixteen years without exploding. It is possible that most, (if not all) ,of the explosive made and sold during the operation of Hall's factory was entirely stable.

John Hall goes on in his letter to declare the original agreement with Schönbein to be void; to arrogate to himself any future disposition of gun-cotton manufacture whatsoever. He does, however, undertake to pay Schönbein a twenty-five per cent royalty of any future profits - if any.

Towards the end of the letter John Hall allows the slightest tinge of recrimination to enter into the correspondence:

"... for we must confess to you that we should never have entered into any agreement or had anything to do with the matter had we not relied upon your express declaration that the gun-cotton could be made for tenpence sterling per pound, a price assumed on fallacious data..."

Letter from John Hall to Professor Schönbein,
London, 23 Lombard St., August 1847
(See above)

What Schönbein's reply to John Hall's letter was is not known. That he was profoundly affected by the loss of life is clear in a letter

which he wrote to the Reverend J.A. Barron* from Basle on the 22nd October 1847. More important to present purposes is that he also expressed his opinion on the probable causes of the explosion:

"My opinion is that the explosion took place in consequence of some inadvertence or other having occurred during the operation of drying the cotton. In other terms, I think it very likely that some portion of gun-cotton was exposed to a degree of heat at which the substance was set on fire. Not knowing at all the manner in which the gun-cotton was dried at Faversham ... I feel quite confident that the preparation of the article is not connected with danger if the process of drying be carried on in a proper manner, i.e. by a current of air moderately heated..."

It can be said for Schönbein that he had from the beginning had misgivings about the whole enterprise. He was a scientist and not at ease in affairs of business. He had expressed his feelings to his wife when he wrote to her from London on the 2nd September 1846.

"Perhaps I may make something of it if I do not lose patience, but this is not easy. In certain respects it is almost a mistake to have made an important practical discovery; it completely destroys one's peace of mind. Faraday and Groves told me the same thing: they continually stood in fear of coming across something which would bring them in contact with the practical world, as I have done..."

The Letters of Jons Jakob Berzelius and
Christian Friedrich Schönbein (1836-1847)
Edited by Georg W.A. Kahlbaum; tr.
Francis V. Darbishire and N.V. Sidgwick,
Pub. William & Norgate, London 1900 (part
of a footnote), p.89.

(The Faversham explosion was followed by even more disastrous accidents at the French Government factories at Vincennes and Bouchet. So far as large scale manufacture of gun-cotton for use as an explosive

*The Reverend Barron may have been the translator of Schönbein's correspondence with Hall; he may also have been the commercial agent for both parties, someone who undertook the calculation of the royalties, and so on. Letters appear to have gone to Barron at Berlin before being passed on to Schönbein at Basle.

was concerned the development of gun-cotton was virtually suspended in both France and the United Kingdom for about fifteen years.

The discrediting of gun-cotton blighted for almost a century afterwards another application which might well have advanced a technology very closely related to that of blasting explosives. In a discussion of the Coroner's findings on the Faversham explosion, there appears in The Practical Mechanic and Engineer's Magazine for September 1847 (p.267) the following:

"It will be remembered that, about three weeks ago since, a similar explosion of gun-cotton occurred at the rocket manufactory of Messrs. Wade at West Ham. They were endeavouring to construct a rocket of gun-cotton which should equal a 12 lb. (31 Kg.) congrève ... (i.e. a rocket of Congreve's design).

At least one firm was prepared to take the risk of working with gun-cotton fully a month after the Faversham explosion.

Other applications for gun-cotton in solution were found after 1847 - so it can be assumed that small quantities were being made. The Chemical Gazette for October 1848 describes 'Preparation of Collodion, or solution of gun-cotton, as an adhesive material for Surgical Purposes, an invention of M. Maligne which was also made by Maynard who used nitrate of potash and strong sulphuric acid. F.A. Nobel is often credited with this invention in popular works. Gun-cotton was also used as a medium for holding the silvering of mirrors).

Gun-cotton in India

News of the new explosive spread to India almost as rapidly as the sea passage would allow. At that time much of India was still under the rule of the Honourable East India Company. 'John Company' was the Government of many of the provinces under its control and as a Government it maintained several large Armies, a Navy, and carried on all manner of

public works. India was where a great deal of British technology was exercised. For many purposes it was an extension of the United Kingdom. British Indian society was as excited about the discovery of gun-cotton as were the people at home. In many ways gun-cotton was of more direct interest in India. Most of the educated Europeans in India were Officers in the Company's forces. The besieging of forts and walled towns was very much a part of soldiering in India then, and much later. But there was also a proper scientific interest. Learned societies, such as the Calcutta Medical and Physical Society, was one of the extensions of British life which thrived in India.

It is particularly interesting to note that the first samples of gun-cotton arrived in private letters. The President of the H.E.I.C., Sir James Hogg, had been present at the British Government sponsored trials of gun-cotton at Faversham during October of 1846, but a small sample had already been sent to Calcutta in time to arrive during December of 1846. The one grain sample was analysed and quickly replicated by Dr. William Brooke O'Shaughnessy.*

A second sample, claimed as the first to arrive in India, arrived at Bangalore in January 1847.

(It would be neither sensible nor particularly useful to attempt to say which was really first to arrive. Bangalore was in the Madras Presidency and more than 300 kilometers up country. Calcutta was 1600 kilometers further away from the United Kingdom but was a direct sea route. They are in effect cities in different countries within the same continent).

The circumstances under which the Bangalore sample arrived were recorded in a letter which was published:

* Gorman Niel, Sir William Brooke O'Shaughnessy: Pioneer Chemist in a Colonial Environment, American Journal of School Chemistry, Vol.46, No.2, Feb.1969, p.101.

"The First Arrival of Gun-cotton in India

A friend in England having sent out a small portion of Gun-cotton prepared by Mr. Horsley,^{*} chemist, Ryde, Isle of Wight, it arrived at Bangalore last January, and it became the universal topic of conversation. The modicum of cotton was carefully preserved and produced at the General's table, where a large party was assembled. On being handed to the Commanding Officer every eye was fixed upon him expecting that he would at once take means to try the experiment, but to the disappointment of the whole party, but still somewhat to its amusement, the General, we suppose thinking the matter too serious for after dinner deliberation, coolly put the explosive in his pocket book. We understand that he afterwards exhibited it to the select few, with admirable effect, and half the medical staff of the station were in the course of four and twenty hours engaged in making gun-cotton, each declaring his was the best...

Practical Mechanic and Engineers' Magazine,
May 1847, p.190.

The Interim Period: 1847 - 1862

From the end of 1847 until 1862 there is very little reference to gun-cotton in English printed sources. It was reported^{**} that during the Crimean War of 1854 - 1856 Lord Armstrong had built, at his Tyneside Factory, the cases of certain submarine mines which were to be charged with gun-cotton. The mines were to be used to block the exit from the Sea of Azov, and thus to confine Russian warships to the River Don. The war was won before the mines could be used. But apart from such isolated experiments the abandonment in the United Kingdom appears to have been complete.

Between 1847 and 1848 gun-cotton continued to be made in French Government factories. At the time of the Bouchet explosion that factory had made 5,000 kilograms of the explosive.

* John Horsley?

^{**} The War in the Crimea, W.H. Russel, Pub. Routledge, London 1856.

Interest was maintained elsewhere on the Continent of Europe. Schönbein offered his patent to the Deutscher Bund, the confederation of the German States, for the sum of 100,000 thalers (Then about £1,250). However, because of internal dissention without the Bund, the offer was declined. Moreover, Schönbein had to wait until 1852 for a decision on his offer. At the 1852 meeting of the Gun-cotton* Committee, which had taken place at Maintz, the secretary was an Austrian, the General,** Baron von Lenk.

Von Lenk took up Schönbein's patent for 30,000 gulden (then about £250). The further development of the manufacture of gun-cotton was carried out in absolute secrecy for almost ten years afterwards:

"It is," says Commandant d'Andlau, writing from Vienna on the 15th November 1861, "a secret which time alone will reveal." No stranger was admitted into the factory at Hirtenburg, where General Von Lenk's method was carried out. The Commandant d'Andlau added that, after most satisfactory trials, the Emperor of Austria had decided on the adoption of a new material for the employment of gun-cotton in all the field artillery."

LXIV. On Gun-cotton, with reference to the New Methods of General Baron von Lenk for preparing and employing this substance. By M. Pelouze, Member of the Institute, and M. Maurey, Commissioner for Gunpowder.***

(The above cited paper gives a most detailed description of Von Lenk's work).

* Usually said to have consisted of Army officers appointed by the Diet, but the chemist Liebig represented Hesse.

** Then 'Captain' Von Lenk.

*** Translated from the Annales de Chimie et de Physique for October 1864, by Dr. E. Atkinson, Royal Military College, Sandhurst. Reprinted Phil. Mag. S. 4. No.192. Suppl. Vol.28, p.535 et seq.

Gun-cotton in the United Kingdom

The Second Phase (1862-1875)

British interest in gun-cotton was reawakened towards the middle of 1862 because of a growing disenchantment with the explosive on the part of the Austrian military establishment.

Under the direction of Baron Von Lenk there had been almost ten years of secret experiment with the manufacture and the application of gun-cotton. The bronze field artillery which had been specially designed to use gun-cotton was declared to be unsatisfactory. The trial had been extensive. Thirty-six batteries of guns had been issued entirely with gun-cotton ammunition. But in use as a propellant the gun-cotton had been adjudged to be not markedly superior to ordinary grades of gunpowder. Moreover, gun-cotton quickly consumed gun barrels because the heat of the conflagration burnt some of the tin out of the alloy. Used as a bursting charge in shells, gun-cotton often exploded before the shell had left the barrel because of the shock of the acceleration. Austrian Artillery officers were, in general, opposed to the use of gun-cotton in ordnance. The Austrian Engineer Committee had, however, reported excellent results when gun-cotton had been used for military mining operations.

The main outcome of the long period of experiment in Austria was some progress towards a more certain method of making a stable gun-cotton.

The principal agent in Austrian work with gun-cotton was dispossessed. Von Lenk had either to find another patron or to attempt to capitalise on his work at Hirtenburg. He began to take out patents* overseas. He made his offer to Great Britain.

At this point it is necessary to modify any impression that Baron Von Lenk was the only man who had maintained interest in gun-cotton. The

* British patent No. 1090 of 1862, which was taken out in the name of Revey. British Patent No. 2720 of 1863.

evidence is only a matter of a few sentences entering into the course of discussions in popular articles dealing with the reintroduction of gun-cotton, but it is clear that interest and experiment had continued in Prussia and in France, and perhaps in Russia, all along. The simple knowledge that Austria had a secret process and had equipped a considerable force with artillery which used gun-cotton was perhaps enough to have ensured a continued interest. General Von Lenk received the publicity because he sought it. There had been a wider and growing interest in gun-cotton before 1862.

Von Lenk appears to have put an official gloss to his promotion, to have given an impression at least that the process was offered almost as from one government to another. This was mere window-dressing. He was after all General, the Baron Von Lenk, and had enjoyed royal patronage until relatively recently. In the event, if Von Lenk had used official lines of communication to foster a private venture, this approach was to prove a decided embarrassment. On 20th July 1863 - while Von Lenk was trying to find support for his process - the magazines at Hirtenburg blew up. Two years later, on 11th October 1865, magazines at Steinfelder Heide, near Vienna, blew up, again without attributable cause. The Austrian government stopped all further manufacture of gun-cotton.

Reception of Von Lenk's offer of his process was, not unnaturally, cautious. The first public announcement of his proposals took place at the 1862 meeting of the British Association, which met that year at Cambridge. A Committee was appointed to examine Von Lenk's claims and to report upon them at the next meeting of the British Association, which was to be at Newcastle in 1863.

At least one member of the Gun-cotton Committee appears to have been able to supply extensive information at once.

"Mr. Scott Russell read the report of the committee on gun-cotton. It stated that General Hay, of the Hythe School of Musketry, had constructed a new form of cartridge suited for the Whitworth rifle; that he had found that the use of the gun-cotton was clean, and did not foul the gun; that it had much less recoil for the same effect ... Thus, therefore, the use of gun-cotton in musketry had been proved by English made gun-cotton, in English rifles, by an English General, to perform all that the committee last year reported on the faith of the Austrian General Lenk....."

The 'Committee on Gun-cotton' mentioned can not have been the same thing as the Gun-cotton Committee of which Mr. Scott Russel was a member. It must be supposed that Von Lenk had approached the British government at some time during 1861.

It will be seen that gun-cotton was already under extensive test for civilian use before September of 1862:

"The next application made during the past year was to the airing of tunnels, shafts and drifts, or the engineering applications. It was stated by the committee that one-sixth the weight of charge of cotton was equal in blasting effect to gunpowder ... At Wingeworth Colliery one-thirteenth the weight of gun-cotton, as compared with gunpowder; at the slate quarries at Llanberi, at Allen Heads ... At Allen Heads, at Mr. Beaumont's lead mines, a canal (sic a drift) was being driven seven miles long. The drift was 7 ft. (2.13 m) by 5 ft. (1.27 m) in the hardest limestone. Both ends were worked by gun-cotton fired by electric battery. The great advantage experienced was that the air was not contaminated by smoke..... The government had appointed a committee representing the navy, the military, and civil engineering, as well as chemical and physical science, and that committee was already engaged in a systematic course of experiments relating to the manufacture and keeping qualities of gun-cotton, and its use in artillery, small arms, and engineering."

The Engineer, 23rd September 1862, p.197.

The above is the only reference to Government interest at this early date which can be offered.

It was after June of 1863 that Austrian government, perhaps in order to protect itself from the effects of any claims made by General Von Lenk, sent to the British government a minutely detailed report on the work carried out by Von Lenk while he was at Hirtenburg. The report of the Austrian government was translated and printed in extenso in the Practical Mechanic's Journal for 1st October 1863 (p.172).

With what enthusiasm the report was treated at the British Association meeting in Newcastle upon Tyne in September of 1863 can be judged from the observations of the correspondent from the Practical Mechanic's Journal cited immediately above:

"Great interest was therefore excited at Newcastle at the late meeting of the British Association, by the presentation of the report* of the above committee, which was read in both sections, but we cannot say discussed ...

The report of the chemical side of the committee was also important and a very long statement of experimental trials and technical details as to the best method of manufacture on the Arsenal scale ... read by Dr. Abel ...

We cannot say quite as much for the report of the mechanical side of the gun-cotton committee, read by Mr. John Scott Russell, for although (causing)** some interesting and curious discussion, it appeared to us to have been framed in a good deal of ignorance of what had been ascertained experimentally, and printed several years since by French Officers and philosophers, and more especially by General Piobert and Colonel Mallett ...

It can be supposed that after the general publication of the Austrian government's report there was little to prevent anyone with the wit to write a clever specification to circumvent Baron Von Lenk's British

* Report on the Application of Gun-cotton to Warlike Purposes by a committee British Association for the Advancement of Science (Newcastle) 1863, p.34 et seq

** The text is faded at this point.

*** This is one of the allusions to work on gun-cotton other than in Austria before 1862 which made above.

patent. This may indeed have been the intention of Von Lenk's unfriends in Vienna.

At the winding up of the 1863 meeting of the British Association, Professor Abel, who was chief chemist to the British War Office, had read a paper which was generally favourable towards the reintroduction of gun-cotton:

"Professor Abel read a short report, giving a description of the Austrian system of manufacture of gun-cotton, and a detailed account of the results of experiments made in this country, with the view of determining the nature and the properties of Austrian gun-cotton. In concluding his report, Professor Abel gave it as his opinion that, under a properly regulated system, the production of gun-cotton was not more difficult and complicated, and was attended with considerably less risk of accident to the workmen and the manufacturing establishment, than the production of gunpowder."

Alfred Abel was fully aware at the time he read his paper before the British Association that the Austrian government had discontinued the use of gun-cotton, in guns.

After 1863 the military and the civilian production of gun-cotton appear more clearly to have diverged. All military gun-cotton was made at Waltham Abbey; all gun-cotton for civilian use was made at the Stowmarket Factory of Messrs. Thomas Prentice and Sons.

The Manufacture of Gun-cotton at Stowmarket

Most accounts of gun-cotton manufacture after 1863 refer to Waltham Abbey or they are simply not positively referable to either of the two factories. Fortunately, an extremely well detailed description of the entire process which was carried on at Stowmarket,* the civilian manufactory, was printed in Engineering for 1st November 1867 (pp.408, 403-431, 467-468). Since this source gives more detail than any of the

* It is believed that work on the Stowmarket factory premises was begun in late 1863.

others found, and because it is most closely contemporary with the first years of the renewed gun-cotton industry, it will be used as the main basis for the discussion which follows.

The patent upon which the 'Patent Safety Gun-Cotton Company' was founded was that of Frederick Augustus Abel: Improvements in the Preparation and Treatment of Gun-cotton, F.A. Abel, Royal Arsenal Woolwich, British patent No.1102 of 20th April 1865. It is noted that Abel offers no improvement in the nitration of the cotton: the improvement was supposed to be in the stabilisation which followed nitration.

Abel's patent differed from Von Lenk's in two respects. After nitration the fibres were pulped, and, where it was wished to slow the speed of the explosion, a proportion of plain cotton fibres was mixed with the gun-cotton.

The pulping of gun-cotton was not an entirely original idea. The practice had been a part of the process of manufacture at Bouchet, in France. It had also been embodied in the specification of British patent No.320, which had been granted to John Tonkin of Poole, Cornwall (sic Dorset?) on the 6th February 1862: Improvements in the Manufacture of Gunpowder.

"The fibre is then taken in the wet state and converted into pulp in the same manner as is practised by paper-makers, by putting the fibre into a cylinder, having knives revolving rapidly, working closed to fixed knives."

(The patent was for a sodium nitrate gunpowder to which three per cent of pulped gun-cotton was added).

Gun-cotton made at Stowmarket was made from cotton linters, short fibres left over from 'willowing' of raw cotton. This material was probably very much cheaper than the long staple cottons used formerly

since it was classed as 'waste'. It did, however, require some considerable preparation:

"This is effected by boiling it in an alkaline solution, then drying it in a centrifugal machine, and then boiling it in clean water. After a second boiling it is again partially dried in a centrifugal machine, and any remaining moisture is thoroughly removed, by exposing the cotton to the atmosphere, and partly by placing it on shelves in a drying chamber heated artificially to about 120⁰.(F.). The drying of the cotton has to be very thoroughly effected, as any moisture ... combining with the acids used for conversion, generate heat and set up a destructive action..."

There was in the new process an emphasis on thoroughness. The cotton was carefully weighed out into lots of one pound (.45359 kg.) each, each hank was put into a small wooden box and the boxes were passed through to the 'converting room'.

"There each charge is placed separately in a bath containing the mixed acids, the mixture in which the cotton is submerged consisting of three parts, by weight, of sulphuric acid and one part of nitric acid, the mixture being allowed to cool down - a process which occupies two or three days - before the cotton is placed in it. After immersion, the charges of cotton are strained until each contains only about ten times its weight of acids, and then each charge is placed in an earthenware jar and covered down. In order to prevent any heating of the cotton taking place, the jars are arranged in a kind of shallow trough, through which a current of water is kept constantly flowing."

A description of the special provision made for venting acid fumes from the room where the cotton was treated with acids brings a recollection of the difficulty which the operatives working at Hall's factory in 1847 had in 'sustaining respiration'. Acid fumes were still a problem. The writer of the article inserts an unfavourable comparison:

"The building in which the conversion of the cotton is effected is ventilated by a shaft in which an artificial current is maintained; but the ventilation can scarcely be called perfect, and it is doubtful whether the fumes arising from the acids could not be more completely by a series of flues connected with the shaft and arranged so as to draw off air from the floor of the room close to the bath in which the acids are contained. This system ... advocated by General Morin (France) has been found effective..."

Nitration in the earthenware jars was allowed to go on for all of forty-eight hours. The need for the jars can be appreciated. Without the use of the earthenware jars to hold a small quantity of cotton there would be a need for a single bath, of the same kind used for the initial dipping, for every hundred pounds or so of cotton.

Because the acid took so long to cool, and because successive dippings would weaken the larger body of acid, the jars allowed the strength of the acid to be locally maintained, and reduced both the time needed to prepare the acid and the number of large containers needed. The strength of the acids in the dipping tank would be maintained as it was topped up with new acid. There may also have been a thought for the safety which would come of keeping the charges separate.

Extreme care was taken to ensure the thoroughness of the washing and drying which the nitrated cotton received:

"... is removed from the jars and placed in a centrifugal drying-machine. On removal ... it is plunged into a strong fall of water, received by a tank, in which the gun-cotton placed in the fall is allowed to remain for a short time. The object of placing the gun-cotton in the fall of water, or 'drench bath', as it is called, is to ensure the sudden and complete submersion of the material, and thus avoid the heating and decomposition of the cotton which would take place at the surface of the water if the cotton were immersed gradually. On its removal from the drench-bath, the gun-cotton is again dried in a centrifugal machine, and then placed in a bath through which a current of water constantly flows for forty-eight hours ... These alternate washings and dryings

being repeated until the gun=cotton has passed through eight baths, successively, remaining forty=eight hours in each."

If the process was truly as elaborate as described it indicates a care which was almost superstitious. A processing time of sixteen days would mean that the quantity of gun=cotton which at any one time was passing through the factory could have been large.

Pulping the newly made gun=cotton was done in an ordinary commercial rag=shredder, 'similar to those employed in paper=mills'. The 'Dutchman' had been in use since at least the middle of the eighteenth century. There were two pulping machines at Stowmarket in 1867.

Following the pulping process some of the gun=cotton was formed into 'gun=paper' or as it was called, 'retarded paper', which was used for civilian small arms ammunition, particularly for shotguns. It is not proposed to take this topic far - all the information available about the material is in the above cited article - however, it can be said that it was made from gun=cotton which had been reduced to a finer state of division than that meant for explosives; it was made 'by the ordinary hand process', and tinted pink.

Gun=cotton intended for mining charges required very much more further processing. This is to be contrasted with black gunpowder which left the mill in barrels and had to be made up into whatever form was required elsewhere. Explosives were beginning to be specialised. Gunpowder could be used for any purpose; it would be less easy to mis=apply gun=cotton mining charges. On several occasions F.A. Abel had pointed out the dangers to civil peace which lay in the easy access which the public had to mining gunpowder.

After being weighed carefully into quantities representing a calculated dry weight of gun=cotton, each unit was pressed into a small tin=plate vessel ready to be carried to the 'pressing house'. That the

gun-cotton was always thereafter kept moist is stressed. As had been the practice at Faversham, 'boys' were employed in the pressing-house. This was also the practice at Waltham Abbey at the same period.

"The hand-pressing is effected by boys as follows: Each charge, after being moistened with water, is transferred from the tin from the tin cup containing it to a cylindrical mould or tube, the external of which is equal to the external diameter of the intended charge..."

At this point there is a description of the way which had been found to overcome a minor but troublesome technical problem. Because both the problem and the way in which it was solved will show the extent of the shift in technical thinking, in the conception of the way in which explosives were to be made and handled, achieved by men whose entire previous experience had been with black gunpowder, the description will be detailed:

The problem was that when it was attempted to force wet gun-cotton pulp into a cylinder to form a cartridge, 'a kind of piston, below which the air contained in the tube became compressed' was formed. The increments of pulp could not be forced home. The solution not only overcame the immediate problem but gave also a bonus:

"This difficulty was got over in a very ingenious manner. Instead of the tubes being made completely closed at the lower end, the latter is perforated, and the solid form on which the charge rests is formed by a kind of piston, with which each tube is fitted. This piston is furnished with a rod which passes up through the centre of the charge, forming a hole through the latter, which enables the charge to be ignited from end to end, by the flash of the portion first lighted. In the case of charges, the diameter of which exceeds 2 inches (5.8 cms.) the pistons of the moulds are furnished with two rods, one of these forming a central hole, and another a hole nearer the circumference in which the igniting fuse can be placed."

It can be seen that even by as late as 1867 it was necessary to

ignite gun-cotton with the spurt of flame from the end of a Bickford fuse - it was a year later that R.O. Brown invented his form of mercury fulminate detonation. The central hole was almost an essential with a compressed charge of gun-cotton: it would have been troublesome to have had to have bored a hole in a material which was at least as tough as papier-mache or a light wood. The description of the hand-pressing part of the process continues:

"... the cotton being first placed in the mould, and pushed in a small distance, the charge is rammed in on top of it, and then on the piston being forced down to the bottom of the mould by the aid of its rod, the atmospheric pressure on top of the charge causes it to be carried down in close contact with the piston. A hollow plunger, perforated at the bottom and sides, is next placed in the mould, the end of this plunger having a hole, or holes, through which the rod, or rods, of the piston can pass; and the whole is then placed under a hand lever..."

Making up gun-cotton mining charges had passed at once into unskilled process work. The need to employ young, cheap labour at work which was neither skilled nor, at that stage, particularly dangerous, is apparent. The same pattern had come into being in the manufacture of other explosives and safety fuse.

Secondary pressing was a fully mechanised process which, from the description, was capable of turning out large quantities of cartridges of densely compressed gun-cotton very quickly. This was essentially a modern means of manufacture - a means of mass production. There was, nevertheless, a need only to adapt existing machinery designs for the work, as can be inferred from the description:

"... resembling a slotting machine in its general appearance. The slide ... instead of carrying a cutting tool, is fitted with three plungers, which act upon each charge successively. The

The charge to be pressed is placed in a cylindrical mould carried by a horizontal circular table, having an intermittent rotary motion..."

(The remainder of the passage describes what is essentially a slotting machine in operation).

The compression of larger blasting cartridges called for a different method.

"This consists of a horizontal hydraulic cylinder, the main plunger of which is furnished with a head carrying a number of small plungers for compressing the charges, these plungers being arranged in parallel rows one above the other... the arrangement is found to be a very efficient one."

Finished cylinders of compressed gun-cotton were pushed free of the moulding block directly into boxes. That Messrs. Prentice and Sons were making large cartridges of gun-cotton indicates that there was at that time some improved means of sinking shot-holes: there is a limit, perhaps of about two inches, (5.8 cm.) upon the size and depth of a shot-hole which may within any reasonable time be sunk by a man battering with a sledge-hammer on a jumper bar.

The wrapping of gun-cotton mining charges was carried out with great care. It is interesting, and a little ironic, that the material used for protecting the finished gun-cotton was also one of Schönbein's inventions.

"The next process undergone ... is that of being covered with a peculiar kind of paper, termed 'artificial vellum'... which is manufactured by Messrs. Prentice on their own works, is made by laying sheets of blotting paper for a few seconds on the surface of strong sulphuric acid contained in a bath ... immediately plunged into troughs containing water ... the artificial vellum being tough semi-transparent substance ... is cut into strips, rolled around the charges, and secured by paste, the operation of covering being performed by girls."

Wrapped and pasted charges were stoved dry at 140⁰F (60⁰C) steam heated drying chamber which was divided up into smaller compartments in order to limit the extent of any accidental ignition of the explosive.

Messrs. Prentice also made for mining purposes gun-cotton in a special form:

"Besides the regular charges ... the firm are now making a peculiar kind of gun-cotton yarn, specially adapted for splitting off slabs of slate. A hole being formed behind the slab being separated, a sufficient length of this yarn is inserted and ignited, no tamping being used. We understand that this yarn is now found to answer its purpose capitally, and that it is now being extensively used in Wales."

It will be remembered that a similar kind of yarn, enclosed in a paper tube, was also sold by Messrs. John Hall & Sons during 1846-47; it too was specifically to be used for splitting off slate.

A note on the Machinery at Stowmarket

When compared with the Schönbein process used at Faversham twenty years before, the new method required very much more machinery, and more power to move that machinery. But most of the machinery was of a kind which could be used without much in the way of modification. Reference to a contemporary* catalogue of industrial plant will not ordinarily show any machinery designated specifically for gun-cotton manufacture; but the component units are there, sometimes the names of the makers correspond with the names on the name-plates shown on illustrative engravings.

Both steam and water power were used at Prentice's works:

*The Practical Mechanic's Journal, Scientific Record of the International Exhibition of 1862. Conducted by J. Henry Johnson (prop. Practical Mechanic's Journal, Ed. Robert Mallet, M.A., M.I.C.E., F.R.S., Pub. Longman, Green, and Longmans, London, 1862.

"... situated by the side of a stream which furnishes a supply of water for washing, and also drives a water-wheel, by which the pulping machinery is worked..."

"The centrifugal drying-machines, which are extensively used at various stages of the manufacture are of ordinary construction, each consisting of a cylinder with wire gauze sides, caused to revolve horizontally at a rate of from 500 to 800 revolutions per minute."

"A number of machines at Stowmarket are worked from shafting driven by a horizontal engine, and others are driven each by a special engine placed to the machine, these engines having their crank-shafts arranged vertically, and the fly-wheel of each engine being connected directly by a belt to a pulley on the spindle of the corresponding drying machine."

The Stowmarket Explosion

At 2 p.m. on the 11th August 1871 there was a series of tremendous explosions at the Stowmarket factory. It was later estimated that fifteen tons (14.75 tonnes) of gun-cotton had exploded. Among those not accounted for afterwards were two of Thomas Prentice's sons, Mr. Edward Prentice and Mr. William Prentice. Damage was extensive. The immediate area of the factory was totally destroyed; other damage extended outwards for a distance of up to four miles.

This event almost resulted in a second abandonment of gun-cotton. The immediate response to the accident was an outcry in the Press calling for the prohibition of all further manufacture. The Government ordered that all work on gun-cotton at its own Waltham Abbey works be suspended, and that the gun-cotton in the magazines at Upnor be wetted.

Fortunately it was later decided that the explosion could only have been brought about by the introduction of strong sulphuric acid into several batches of gun-cotton which had already been subjected to the tests required by the government. The verdict was that the acid

had been added to the gun-cotton by some malicious person, not discoverable, who was perhaps not able to predict the outcome of the act. The evidence was said to be circumstantial, but of a more than ordinarily strong kind. After an exhaustive enquiry the manufacture of gun-cotton was allowed to continue.

If the accident had served any useful purpose it was to - virtually - precipitate the comprehensive statutory control which was embodied in the Explosives Act of 1875.

Two final quotations concerning gun-cotton are given here. The first is from the testimony of Mr. Manning Prentice to the Stowmarket Inquiry; the second is taken from the wording of the later government Committee of Enquiry into the manufacture of gun-cotton.

"We had thought we had to deal with a combustible, not with an explosive."

The Engineer, 25th August 1871, p.129.

"The Committee ... consider that its use is not only unattended by either uncertainty or peril, but that the material as an explosive agent is effective, certain, safe, portable, and easy in employment ..."

The Engineer, 19th January 1872, p.37.

The decision to proceed with the development of gun-cotton took under six months.

Gun-cotton in Use

It was in military applications that the high explosive properties of gun-cotton were at first appreciated:

"It is a well-known fact that a bag of gunpowder nailed on to the gates of a city will blow them open. A bag of gun-cotton exploded in the same way produces no effect. To blow up the gates of a city with gun-cotton it must be confined before

explosion. Twenty pounds of gun-cotton carried in the hands of a single man would be sufficient, only he must know its nature. In a bag it is harmless, exploded in a box it will shatter the gate to atoms. Against the pallisades of a fortification, a small square box containing 25 lb. (11.4 kg.), simply flung down close to it will open a passage for troops..."

The Engineer, 4th September 1863, p.136.

(This particular kind of explosion was popular in exhibitions of gun-cotton used for military purposes: a hole was blown in a section of pallisade, ready for infantry to enter the breach immediately afterwards).

Nevertheless, the high explosive potential was at least noted by civilian users:

"With gun-cotton ... it being found that it exerts a powerful splitting action below as well as above the point where the charge was situated. This effect appears to be due to the extremely rapid action of the gun-cotton; but, whatever may be the cause, it is an effect which is regularly found to occur in practice, and one which makes gun-cotton particularly valuable for quarrying purposes..."

Engineering, 15th November 1867, p.467.

Those properties of gun-cotton which were appreciated in civilian work, especially those which were carried out underground, were the near absence of smoke, which allowed workmen to return quickly to a face after the shots had been fired, and the relatively innocuous nature of the fumes given off by the explosion. When gun-cotton was found to give off smoke and fumes it was claimed that it was because a wastefully large charge had been used, which was supposed to result in an imperfect combustion of the gun-cotton. No workman's testimony on the matter can be cited. Again, the introduction of detonators is likely to have reduced any smoke or fumes which would have been generated when gun-cotton was merely ignited.

Probably the most extensive and detailed trials of gun-cotton for civil use were those held at Green Thorn Quarry, Allenheads, in

Northumberland during October of 1864.* The trials were instituted by a Mr. Beaumont, M.P. who was also the owner of the mines and quarries used for the trials. Gun-cotton was used exclusively and the experiments took place both in an open quarry and at workings underground. At Allenheads the rock is a hard limestone. Since the account of the trials is very long, only a synopsis of the important points will be given, with a few quotations where these will illustrate a point economically.

Two forms of gun-cotton were used at Allenheads: granulated and compressed. The source of the gun-cotton is not given. Granulated gun-cotton was said to have been prepared by mixing dry gun-cotton with about 3 per cent of gum arabic and then adding just sufficient water to wet the mixture. When rolled in a drum, the gummed cotton took the form of small granules or floccules. This sounds very much like Abel's patent method. Compressed gun-cotton was prepared by cutting pieces of from one quarter to one half of one inch (6 mm - 12 mm) across from slabs which had been pressed from pulp under a pressure of fifty pounds (3.5 kg/cm^2) per square inch. Both kinds of gun-cotton were sent up to Allenheads in 'cylindrical pasteboard cases of one inch diameter and upwards.' 'All holes were fired with the ordinary miner's safety fuse which was inserted before the entire charge had been introduced, as is the practice with gunpowder.'

There was a careful regard for safety during the Allenheads trials, especially in the placing of charges:

"After the charge was inserted into the holes and pressed down with the wooden rod, a plug of cotton waste was pushed down for the purpose of carrying to the bottom any particles of the gun-cotton clinging to the sides of the hole. The latter was afterwards tamped, as usual, first with clay, and afterwards with debris of limestone in a nearly powdered state."

* Spon's Dictionary of Engineering by E. & F.N. Spon, Ed. Byrne, Charing Cross, London, 1870, Vol.III, p.1770 et seq.

Shot-holes bored for the experiments were surprisingly shallow, when compared with those sunk elsewhere to test nitroglycerine. Thirty inches (76 cm.) is the deepest recorded; the least deep was fourteen inches (36 cm.). The diameter of shot-holes was nominally one and one eighth inches (3 cm.), though it was stated that those sunk in the hardest limestone tapered towards the bottom. A short reference to a drilling machine of some kind is particularly interesting because, as has already been said, there was a practical limit to the depth of shot-hole which could easily be sunk by hand.

"... the greater rapidity of explosion of the gun-cotton when in the form of light granules; it may also, in some measure, be due to the circumstance that, in a hole charged with gun-cotton in the form of grains or small fragments, the charge is in contact on all sides with rock, which is not the case when gun-cotton rope is employed, unless the hole is perfectly cylindrical, which it very seldom is. This remark does not apply to those made by the boring apparatus of Percy Westmacott, which is partially in use at Allenheads Mines, and by which a perfectly cylindrical hole is effected..."

The recording of each individual shot fired is concise and matter of fact. There are, however, many of them and little purpose would be served by extensive quoting. Number seven of the shots fired in the mines at Allenheads is short but entirely representative of the many others:

"A hole 15 in. (38 cm.) deep, driven almost horizontally into the rock, was also charged with 1 oz. (28 grams) of compressed gun-cotton. In this instance, again, a portion of the hole was not blown away, but this result may have been, to some extent, due to an unsoundness of the hole at the base, which was discovered after the explosion."

The results, the conclusions, of the Allenheads Trials were that the granulated gun-cotton was more effective as a blasting agent than

equal quantity of gun-cotton rope. Compressed gun-cotton in the form of 'small lozenge shaped fragments' was said to exhibit a superiority over the granulated gun-cotton because it occupied less space.

Techniques for using gun-cotton in civilian demolition works were very surprisingly modern: the almost elegant demolition works we are accustomed to see on film and television, the collapsing of cooling towers and the like into their own bases so as to limit narrowly the range of damage from falling debris, were practised at least as early as 1875, and perhaps earlier. The following is an example:

"... on the eighteenth ult. demolished the chimney by means of compressed gun-cotton fired inside the chimney by means of electricity. At first a charge of 5 lb. (2.3 kg) of gun-cotton was simply placed inside the base of the chimney and fired, the result being to shake the whole structure and to develop the cracks. A second charge of 8 lb. (3.6 kg), was then fired in the same way; it rent the chimney from top to bottom with huge cracks, but it only brought down one considerable mass, leaving the whole structure divided up into segments. A third charge of 8 lb. (3.6 kg) was fired, when the whole mass came to the ground, huge blocks of masonry detaching themselves and falling in succession, until only some twenty feet (6 m.) of the chimney was left standing ... the object of firing these three charges was to disintegrate the chimney as much as possible so that it might break up in falling, and so avoid injury to the surrounding buildings. The whole mass fell close around the base, doing hardly any damage.

Illustrated London News, 10th September 1875

What amounts to an anecdote in the history of explosives occurred in February of 1875. The surrounding circumstances are simple enough.

F.A. Abel gave a small demonstration of gun-cotton in use to three members of the government, Mr. Gladstone, Mr. Lowe, and Mr. Ayrton. The demonstration went wrong and the windows of one of the inner courts of the Treasury, where the demonstration took place, were shattered. That

the Press was almost silent about the matter, and that the Cotton Gunpowder Company went so far as to utter a disclaimer that it was their powder which was used, aroused comments in such magazines as Engineering. The form of the demonstration is, however, extremely interesting:

"... to wit the cutting in sunder of a balk of timber placed in the courtyard and encircled with a girdle of gun-cotton rope..."

Engineering, 9th August 1872, p.100.

The Transport and Storage of Gun-cotton

The railways appear to have accepted the carriage of gun-cotton more or less readily within the rules already in force for other explosives and combustibles. Only one trial appears to have been recorded during the second phase of gun-cotton development. And since there was only one manufacturer of gun-cotton proper, other than the government, it may be that this was the only demonstration needed. The most detailed account found was in the magazine English Mechanic; shorter references to the same trial occur from time to time as part of articles of general interest in like journals. This may also indicate that only a single trial took place.

However, railway confidence, along with general public confidence, was shaken very badly by the 1871 Stowmarket explosion. The work was all to be done over again.

Carriage of Gun-cotton by rail

"We are in receipt of particulars of an interesting experiment lately made at York for the purpose of determining the amount of risk to be incurred in the conveyance of compressed gun-cotton charges by rail, made by Mr. Prentice, the Managing Director of the Gun-cotton Company.

A small box of cotton containing 125 charges ... was taken into a field. A fuse was inserted and lighted. When the fuse reached the gun-cotton there was a great blaze like the burning of a heap of loose straw, but no explosion ... the box was of wood about half an inch (1.3 cm.) thick, and was nailed, but not bound with iron, at the corners; it was one of the ordinary packages used for sending the cotton out.

Several charges were then laid on the rails near the coal depots of the North Eastern Railway and coal waggons run over them; some were ignited, others were not. Some of them were placed so that an engine should pass over them: they were all ignited ... In all cases the ignition was produced by concussion... The results of the experiments convinced the railway company's agent that gun-cotton may be carried with safety along with other goods in ordinary waggons, adopting the same rules as now apply to the conveyance of cartridges."

English Mechanic and Mirror of Science,
1st May, 1868, p.124.

The Position of the Patent Safety Gun-cotton Company

Messrs. Prentice and Sons of Stowmarket held by far the most important place in the production of nitro-cellulose explosives for many years. Later there were other kinds of nitro-cellulose explosives, but these were made from wood, peat, rags, esparto-grass, and so on. They are for the most part known only by their patent specifications. All had to reduce the base material to a form suitable for nitration, which made for higher manufacturing costs. One of these explosives, Schultz Powder, will be treated in this work.

The position of Messrs. Prentice and Sons in 1871 is given in the following extract:

"In this form and under this title (Patent Safety Gun-Cotton) gun-cotton has assumed in this country an importance far greater than it has at any time in any other. It is now largely employed for blasting slate ... in Great Britain, and its manufacture has

reached the amount of 100 tons (98.5 tonnes) per annum. So increasingly great is the demand for this article that Messrs. Prentice are at the present time engaged in the multiplication of their power of production to four times its present capacity."

Engineering, 28th April 1871, p.297.

CHAPTER 6

NITROGLYCERINE

(1846 - 1869)

This section of the work will give consideration to the discovery and later use of nitroglycerine as an explosive, that is to say, to the use of the pure nitroglycerine in its liquid form. Material dealing with the use of nitroglycerine in its unstabilised form in the United Kingdom is - apparently - scarce. This is not perhaps so surprising when it is considered just how short a span of time lies between its introduction into the country by Nobel in 1864 and its effective prohibition by the terms of the Nitroglycerine Act of 1869. Allow beyond this that it no doubt took some time to promote the use of the explosive after its introduction; allow also that the accidental explosions which occasioned the legislation and the invention of Dynamite Number One both served to pre-empt the legislation, and it will be seen that the actual period when nitro-glycerine was used for blasting in this country was no longer than a few years. It is with these few years that this section will be concerned.

However, to enter into any discussion of nitroglycerine, as it was used in the United Kingdom, directly, without even a short preamble, is thought to be too abrupt an approach. It will be necessary to devote a few paragraphs to the discovery of nitroglycerine; to say a little of the inventor, to outline the quarrel which arose over Sobrero's primacy of invention, and to make a few short observations on the conditions prevailing with regard to the science and technology of explosives at the time of the invention.

Sobrero's Discovery of Nitroglycerine

Ascanio Sobrero was born at Casale on 12th October 1812. At the

age of twenty he took a degree in medicine at the University of Turin. He did not, however, practise medicine - instead he worked as a chemist in a private laboratory. In 1840, Sobrero went to Paris where he worked under Theophile Jules Pelouze. Sobrero evidently impressed his master for Pelouze was to write of him:

'I have never known a young man more zealous, more industrious, more capable than he.'

The great Liebig praised Sobrero with a like enthusiasm when, in 1843, the Italian went to study in Germany.

In 1845 Sobrero was appointed to one of two chairs of Chemistry at Turin. It was here, as Professor of applied chemistry and mechanics, in late 1846, that Sobrero began a series of experiments on the nitration of sugar, rubber, dextrose, mannite, lactose and glycerine. This part of Sobrero's work cannot be treated deeply here. The quotations given below, however, are taken from a translation of Sobrero's original paper. The source is, so far as is known, the only extensive one available in English: Historical Papers on Explosives by George W. MacDonald, M.Sc. (Melb.), Whittaker & Co., London, (1912), pp.160-163.

"Glycerin, under certain circumstances, is very readily oxidized. Nitric acid reacts on it very energetically, producing oxalic acid, and, in all probability, intermediate compounds of a more complicated nature are formed. If concentrated nitric acid or a mixture of two volumes of sulphuric acid of 1.84 sp.gr. and one volume of nitric acid of 1.5 sp.gr. is added to glycerin, concentrated to a syrupy condition, a very violent reaction is set up, with the evolution of very considerable quantities of oxides of nitrogen. If, however, we reverse the process..."

Sobrero counsels the addition of the glycerine to the acids, and that the acids should be chilled. It is worth pointing out that Sobrero mentions the use of nitric acid alone before he mentions a mixture of

acids. Nowhere, in MacDonald's translation of Braconnot's 1833 paper, is there mention of anything but unmixed nitric acid being used in the preparation of nitro-starch. And, as will be seen presently, Sobrero used sulphuric acid in a way which suggests that he was well aware of its strong affinity for water.

"... and pour the glycerin into a mixture of acids kept at a temperature of several degrees below zero, the reaction is quite different. The glycerin goes into solution in mixed acids, and with greater readiness by constant stirring. When the glycerin has been completely dissolved, the contents of the vessel are poured into distilled water at ordinary temperature."

Dissension arose when Sobrero wrote to Pelouze telling of his discovery of nitroglycerine, and claiming that he had also discovered certain nitro-sugars. Unfortunately, Pelouze had then recently described the work of Flores, Domette, and Minard in the nitration of sugars, in Comptes Rendue. Sobrero, however, claimed for himself an absolute precedence, even for the conception of the work which led to the discovery.

Pelouze, while he arranged to have Sobrero's communication published in Comptes Rendus, annexed to the paper a claim that Sobrero had made the discovery years before when working in Pelouze's own laboratory. The implication, and the etiquette of the thing, was that Pelouze, as master, was entitled to credit for the discovery of his apprentice. Pelouze was, of course, a Frenchman; Sobrero was an Italian and a passionate supporter of the Risorgimento.

Throughout his life Sobrero was to claim, for Italy, that the discovery of nitroglycerine had been made by himself, alone, when he was Professor at Turin. Oscar Guttman, in a footnote to the historical introduction in the first volume of his treatise on the manufacture of explosives makes a point of mentioning:

"The author was once specially requested by Professor Sobrero to ... emphasise the fact that the invention was made in his own laboratory when Professor at Turin. He was an Italian, with strong patriotic feelings, and seems to have been specially sensitive on this point."

The stance taken by Pelouze for France can also be understood. Having, in the work of Braconnot, established a claim to the discovery of the generally applicable practice of treating organic substances with nitric acid, it was no doubt frustrating to French nationalism to be thwarted by, first, Schönbein with gun-cotton, and then by a French-trained Italian chemist, in the case of nitroglycerine.

Sobrero announced the discovery of the compound which he proposed to call Piroglycerina in a paper presented to the Turin Academy of Science. The paper which was dated 21st February 1847 was entitled Some new fulminating products obtained by the action of nitric acid on some vegetable organic substances.

Of the other substances - sugar, dextrine, lactine, mannite - which Sobrero had treated, all were more or less explosive in character. Nitroglycerine was remarkable because it was found to be an exceptionally powerful explosive.

During the months which lay between initial discovery, 'late in 1846', and his publication in February of 1847, Sobrero had taken pains to make a thorough study of nitroglycerine. Much of his paper is concerned with the pharmacological properties of his discovery, which clearly Sobrero considered to be as important as the explosive.

"Drops of an oily liquid immediately collect at the bottom of the vessel containing the water, and finally join together to form a distinct layer ... Nitroglycerin can be readily freed from adherent acid by washing with water, in which it is insoluble, and, on placing it in a vacuum over

sulphuric acid, the traces of adherent water are absorbed and a transparent liquid obtained. It is of a light colour, highly refractive, and remains liquid down to a temperature of -20°C . It is soluble in alcohol and in ether and may be obtained in a high state of purity by dissolving it in alcohol and reprecipitating with water ... the properties of nitroglycerin are remarkable..."

Sobrero goes on to give a detailed account of the properties of nitroglycerine, particularly of the conditions under which he found it could be induced to explode.

Discovery is not development. Ascanio Sobrero continued in his connection with nitroglycerine. But it was as a subordinate. In later years he was employed by Nobel as consulting chemist to the Avigliana dynamite factory.

There could hardly have been a less auspicious time for the discovery of nitroglycerine. Schönbein's discovery of gun-cotton eleven or so months before Sobrero published his paper, must have diverted much attention - and also much journal space - from Sobrero's announcement. By February of 1847, interest in gun-cotton - for which applications were apparent - had turned to excitement. There may have been little notice of papers published in Italy. Italian, in the 1840's, had not resumed its place as a majority scientific language. Certainly, there was likely to be no place for any papers by Sobrero in the French journals.

If Schönbein's discovery of gun-cotton obscured the advent of Sobrero's nitroglycerine, the general abandonment of gun-cotton after the disastrous explosions at Vincennes, Bouchet, and Waversham must have done much to ensure nitroglycerine's relegation to the position

of a dangerous chemical curiosity for the next fifteen years.

And finally, something can be said of Sobrero's own attitude to the compound he had discovered. He himself looks not to have considered nitroglycerine to have been any more useful than any of the other nitro-compounds he had discovered. Again, quoting from MacDonald's translation, Sobrero wrote some five months after the first publication of his paper:

"The greater number of these explosive bodies have shown themselves to be unstable. It is only a question of a longer or short time before they begin to decompose with production of nitrogen dioxide..."

Few English language sources make more than passing reference to the important contribution made to the chemistry of explosives by the work of Sobrero. This is understandable. At the time, the organisation of communication, even in the sciences, was not well developed. The material for this section of the present work was sparse; it would have been even more sparse had it not been for the finding of a single American article which not only gave more biographical details of Sobrero than could be found anywhere else, but also gave reference to a number of contemporary and near-contemporary books and papers in the Italian language which, were there an opportunity, could lead to a much more detailed study of Sobrero and his work.

The article was Nitroglycerin: The Explosive Drug by Linda Culp Holmes and Frederick J. DiCarlo, College of St. Elizabeth, Convent Station, New Jersey 07961, which appeared in Journal of Chemical Education (U.S.A.) Vol.48, Number 9, September 1971. The 'Literature Cited' appendix to the article gave the following sources:

1. Fino V., "Ascanio Sobrero", Torino 1889, pp.6-8,12, 22-24.
2. Sobrero, A., Compt. Rend. 25, 247 (1847).
3. Sobrero, A., "La Nitroglycerina, La Nitromannite e La Cellulose Nitrica," Academia della Science di Torino, Vol. V, 1870, p.670-677, 678.
4. Sobrero, A., Comp.Rend., 83, 351, (1876)

The Connection between Sobrero's Discovery and Nobel's

Application of Nitroglycerine

The link between Sobrero's discovery of nitroglycerine and Nobel's development of it into a useable explosive was a relatively direct one. Nobel was, when he was a young man and was living in St. Petersburg, a student of the Russian Scientist, Professor N.H. Zinin. Zinin had worked with nitroglycerine for some time before 1863 with his colleague, the chemist, V. Petrushevskii.*

The Advantages offered by Nitroglycerine

The greatest expense in the carrying out of a blasting operation lay not in the cost of the powder or the nitroglycerine used, but in the labour and the time expended in battering a shot-hole into the rock. The terms of the cost = benefit equation for an explosive was cost of powder plus the cost of placing the powder, against the quantity of rock sundered. This would be well understood by miners. The Engineer of 12th November 1865 (p.85) was at some pains to present this point to its readers by quoting the inventor:

"... From a paper addressed by him (Nobel) to the Academy of Sciences we learn that the chief advantage which this substance ... possesses is that it requires a much smaller hole or chamber than gunpowder does, the strength of the latter being scarce one tenth of the former. Hence the miner's work, which according to the hardness of the rock, represents five to twenty times the price of the gunpowder used, is so short that the cost of the blasting is reduced by 50 per cent ..."

* Chemical Engineering News, Vol. VL (1967), p.114.

The actual point of advantage probably was that the diameter of the hole needed to be much less than was usual when other explosives were used. The amount of explosive which could be put in position could be no greater - in hard rock - than the capacity of the extreme end of the shot-hole. And with an ordinary steel jumper bar (or, indeed, with a compressed air driven rock-drill) there was no way in which the shot-hole could be enlarged to take more explosive without enlarging the boring along its entire length. A sledge-hammer will more quickly drive a thin jumper bar into rock than it will a thick one.

It might be said that nitroglycerine's only advantage lay in its ability to shatter hard rock: the harder the rock the greater became the need to derive the maximum result from the minimum effort in sinking the shot-hole. Where the rock was softer it may well have been more economical to use a less powerful, cheaper, explosive. F.A. Abel remarked upon the somewhat specialist applications open to nitroglycerine:

"In Wales, it was used by some quarry-owners as a most efficient agent for tunnelling and for removing the hard rock overlying the slate...".*

Nitroglycerine would have been unlikely to have been used in situations where it was the aim to extract the rock rather than just to shatter it.

The Manufacture of Nitroglycerine

No descriptions of the manufacture of nitroglycerine in the United Kingdom for the period 1862 - 1875 can be offered. The very many accounts which can be found in the journals and chemical texts of the period are of foreign provenance. That this should be so can be explained. Nobel's patent for a relatively safe method of manufacture gave him legal protection in the United Kingdom. No chemist making the

* Institution of Civil Engineers, Vol.XLV, 14th May 1872, Paper No.1342 - "Explosive Agents applied to Industrial Purposes (p.341).

explosive illicitly would wish to have the fact advertised in a journal; and after 1869, as we shall see, the compound was for a time under severe proscription.

For the above given reasons the two principal extracts cited here are from overseas sources which were published in the English journals. The first gives the essentials of Nobel's process. This is important in itself. The second is a description of the on-site manufacture of the explosive in the U.S.A., where nitroglycerine looks to have been much more readily accepted and more boldly applied than it was in this country. The American material is used because of the clarity of detail it offers.

Alfred Nobel manufactured nitroglycerine commercially in 1862 at a factory which he had built for the purpose at Heleneborg, near Stockholm. After the Heleneborg factory had been wrecked in an explosion, Nobel worked out a modification to his original process of manufacture. It was this process which was embodied in Nobel's British patent, No.1813, of 20th July 1864.

In the original process the glycerine had been added in a fine trickle to the chilled mixture of acids. The relatively small increment of glycerine going into a large body of strong acids was thought to lead to an increase in the probability of decomposition and explosion. To avoid this, Nobel mixed the glycerine and the sulphuric acid together first. Only when the reaction between these two had been completed was the nitric acid then slowly added.

The whole of the reaction with the nitric acid was not allowed to rise above 4.5 C.

The process was economical. If, when the first formation of nitroglycerine had been decanted, the temperature of the remaining acid was lowered to -10°C ., a further proportion of nitroglycerine separated out, the spent acids could be regenerated.

As an alternative to the above, Nobel suggested a direct and rapid method for the production of nitroglycerine. The entire charge of glycerine was to be poured at once into a mixture of two parts of sulphuric and one part of nitric acid. The mixture was to be stirred very briskly and then poured quickly into an excess of cold water. The heat evolved in this kind of reaction was alarming. But the yield of explosive was such as to show that very little nitroglycerine was lost by decomposition.

The first method would seem to have been more suited to the larger scale of manufacture; the second would perhaps have been safer to use in small-batch production.

Nobel also suggests in his patent specification that the 'monohydrate of phosphoric acid' (probably Meta-Phosphoric Acid 2 HPO_3) could be used to fulfil the function of the sulphuric acid in the reaction; the absorption of the water released by the action of the nitric acid upon the glycerine.

Mowbray's Preparation of Nitroglycerine for the Hoosac Tunnel

"The nitro-glycerine is made at the laboratory constructed for the purpose near the shaft, under the direction of Mr. George M. Mowbray, who has recently made some valuable improvements in its manufacture. They frequently make here 150 lb. (68 Kg) daily. On entering the converting department of these works the first object which attracts the attention is a long trough resembling a manger for feeding horses, about three feet (91 cm.) above the floor, and fifty feet (15.24 m) in whole extension, filled with ice and a little salt.

In this, about two feet (61 cm.) apart, are earthen jars holding a gallon (4.546 litres) each, their tops projecting two or three inches (6 cm - 8 cm) above the ice. In these jars are the nitric and sulphuric acids. Immediately over the jars, two feet above, resting in a wooden rack, are inverted cans,

holding about one quart of glycerine. This drops into the acid below, where the reaction takes place, and nitroglycerine is formed, which falls to the bottom of the jar. Mr. Mowbray agitates his acids with cold air. For this purpose he leads the cold air resulting from the partial expansion of compressed air into the laboratory through iron pipes, and over each jar of acid is a cock to which a rubber tube is attached. On the end of this is a glass tube. During the reaction in the jars, and while dense volumes of nitrous oxide are evolved, and the heat which it is necessary to constantly keep down is rising, his men stir the mixture with these glass tubes, admitting a current of cold air which agitates, cools, and in escaping carries off the gas it is so essential to get rid of, as soon as possible after it is formed.

The next part of the process is the removal of these jars, and the emptying of their contents through a trap or square opening in the centre of the floor, into a reservoir holding about forty gallons (182 litres) of water, for the purpose of washing off all traces of acid.

After washing the nitroglycerine, the reservoir, which is balanced on two journals, is turned over on its side gradually, and the nitroglycerine emptied into glass and earthen receptacles. These are removed to a magazine, a few rods (5.5 yards: 5 metres) distant.

At the time I entered this magazine there were one thousand pounds of nitroglycerine there in jars, holding from three to five gallon (13.6 litres - 18 litres) each, resting on benches.

Mr. Mowbray prepares his own nitric acid nearby, and also concentrates the sulphuric acid he employs. It is probably by close attention to the quality of the materials he employs, and through agitation and carrying off of the nitrous acid gas...

Forty two pounds (92.6 kg.) of glycerine yield him ninety four pounds of nitroglycerine, which, at a temperature of 48 degrees and upward is perfectly transparent and without colour. A little below this temperature it becomes frozen, and resembles then pounded ice...

... formerly when they (the workmen) used the imported article (nitroglycerine) which was more or less yellow and brown, they were affected with intense headache...

Mr. Mowbray ... concludes that the agent may be transported quite safely in the frozen state."

Manufacturing of Nitroglycerine,
Engineering, 23rd October 1868, (p.376).

It can be supposed that the practice of lining the tin canisters used for carrying nitroglycerine with a coating of paraffin wax, which was adopted by G.M. Mowbray in the United States might have much reduced all hazards except those associated with explosive chemical decomposition or with gross-mishandling.

Small-scale Preparation On-site

No reference is made in any of the sources consulted to nitroglycerine being prepared immediately before use at any quarry or mine in the United Kingdom. This is not to say that such preparation never took place. The passing of the Nitroglycerine Act may well have led to the illicit preparation of the explosive. It would have been a nice point of law that no offence could be said to have been committed until the reaction was completed. The following paragraph may indicate that the writer knew something of a trade in illegal nitroglycerine:

"At that period, nitroglycerine, one of the most dangerous explosives known, had been recently introduced into commerce, and so valuable were its rending properties to mine and quarry proprietors, that almost any risk was incurred in order to secure its possession. So highly remunerative, too, was the oil to its manufacturers and those who traded in it, that the most unscrupulous measures were frequently resorted to in carrying on the traffic in it."

Engineering, 1st May 1874, p.319.

It will be seen presently when the example of the cans of nitroglycerine which caused the Newcastle Explosion of 1867 is cited that it was not unknown for nitroglycerine of doubtful origins, in unmarked cans,

to be found. The cans at Newcastle could very well have been such contraband. The city was at that time a well-known centre for chemical manufactures— particularly for sulphuric acid.

It is noted that it was the 'mine and quarry proprietors' who were so anxious to get hold of the explosive, not, as might be supposed, the workmen, who commonly had to pay for the powder they used. Many of the proprietors were in those days also J.P's. Some notion of the extent of the trade in illicitly prepared nitroglycerine might be gained if it were possible to find out something of the number of cases brought before the courts for this offence. Accounts of the testimony given would be revealing.

The most likely user of the prohibited nitroglycerine would have been a civil engineering contractor in a hurry to finish a job, rather than the established owner of a quarry or a mine. The attraction was, of course, that nitroglycerine still offered — even after the introduction of dynamite — the greatest and quickest return of rock broken for the least amount of arduous and slow boring done.

On-site preparation was, however, common practice on the Continent:

"It is better, as advised and executed under the direction of Dr. E. Kopp, at the Saverne quarries, to have the quantities required for daily use prepared on the site by intelligent workmen..."

A Handbook of Chemical Technology,
by Rudolf Wagner Ph.D. (Tr. W. Crookes, F.R.S).
London 1872, p.155.

The ease with which the explosive could be made on the site where it was to be used was unlikely to have escaped those who were prepared to break the law.

Nitroglycerine in Use

Few detailed descriptions of how liquid nitroglycerine was used in blasting in the United Kingdom can be found in the journals of the

period. Articles describing the use of nitroglycerine in the blasting of rock commonly cite foreign language sources - Swedish or German - for their material. This may be no more than an indication that it was then easier, from a practical point of view, to copy up a foreign source rather than to send a man to Wales or Cornwall to report on the usage there. It may, indeed, have been thought useful to use the medium of the magazine to advertise the explosive and to offer some instruction in its use. The Engineer published the following short article on 12th November 1865.

"The process is very easy: if the chamber of the mine presents fissures, it must first be lined with clay to make it water-tight; this done, the nitroglycerine is poured in, and water after it - which being the lighter liquid remains on top. A slow match (sic. Bickford fuse) with a well-charged percussion cap at one end is then introduced into the nitroglycerine ... there is no need of tamping. On 7th June last ... the tin mines at Altenburg in Saxony ... a chamber 34 millimetres in diameter, was made perpendicularly in dolomite rock. At a depth of 8 ft. (2.44m.) a vault filled with clay was found, in consequence of which the bottom of the hole was tamped leaving a depth of 7 ft. (2 m.). One litre and a half of nitroglycerine was then poured in; it occupied 5 ft. (1.5 m.)... the mine (was) sprung. The effect was so enormous as to produce a fissure 50 ft. (15.25m) in length..."

Galignan's Messenger

In use, nitroglycerine must have presented a few new technical problems. Used as a liquid it could only be poured down a bore-hole, unless it was first contained in a cartridge of some kind.

(This may offer explanation of the following event which was published in Fordyce's Historical Register of Remarkable Events for 1875).

"December 18 - A miner named Thomas Green, accompanied by his son, a lad of twelve years, was proceeding from Shotton Colliery to Haswell (Co.Durham) ... he picked up upon the foot-path a curious looking thing resembling a lead pencil ... he handed it to his son, who drew his attention to a split at one end of it, and on the lad picking with this with a pin some milky white fluid oozed out into the hollow of his hand. An instant after ... loud explosion ... blowing off the thumb and finger ... what the nature of the article Green picked up was could not be even guessed at."

(It is surprising that a miner should not have recognised the cartridge, and that there should be some mystery as to the nature of the thing in a mining district).

There was a danger that the rock into which the bore-hole was being driven would be fissured. Nitroglycerine liquid poured into such a hole would, at best, be lost; at worst, it could remain at a slightly lower level to blow up when the next bore was driven. The practice of caulking a fissured bore-hole with clay was to prevent the explosive from leaking away. Water poured into such holes to test their soundness would serve the additional function of providing some measure of stemming for the charge; though it was one of the advantages claimed for nitroglycerine that it required no tamping.

The Transport and Handling of Nitroglycerine

Only mercury fulminate could be said to approximate to nitroglycerine in its sensitivity. But unlike mercury fulminate, which was made in relatively small quantities and then used to fill percussion caps where it was rendered generally safe, nitroglycerine was made in some considerable quantity and had, for the most part, to be transported to where it was to be used.

Nitroglycerine was more powerful than any explosive brought into use before it. It was also dangerous in its manufacture, in transport, and in use.

(It appears to have been stable over long periods when stored. Sobrero is said to have kept a jar of nitroglycerine in his laboratory for thirty years without mishap. Similarly, Berthelot kept a specimen, apparently unchanged, for ten years).

From the outset the Railway Companies refused to carry nitroglycerine. This prohibition was to remain - against both nitroglycerine and, later, dynamite - until 1893. The neglect of the road system which the growth of the railways had caused had only begun to be remedied in the early 1860's. Water transport was to become a favoured mode of transport for explosives. Several of the biggest nitroglycerine disasters which were to lead to the general abandonment of the use of nitroglycerine occurred while the liquid explosive was being unloaded from ships.

This need to carry nitroglycerine for some distance from its place of manufacture was quickly to point up a serious limitation to the level of safety which could be assured during the carriage of explosive liquids. The container technology available was no longer adequate.

(And what is said here of nitroglycerine - as the extreme cause - holds for other explosive or highly inflammable liquids which were beginning to be produced in large quantities after 1860. Petroleum, nitrobenzene, the ethers, naphtha, kerosene/paraffin-oil come to mind as examples).

At the time that nitroglycerine was introduced for use there was a remarkably small range of disposable containers available. Though it should be said that nitroglycerine liquid was not in use for long enough to allow safe containers to be developed to hold it.

Glass and earthenware demijohns were readily available, they were mass-produced, they were perfectly impervious, and, above all, they were cheap; but they were also fragile, and they were of a nature which transmitted external shock strongly to their contents.

The hand-made oaken keg which had been brought to so high a state of excellence in England for the carrying of gunpowder could not be used for nitroglycerine. It was expensive, much of the cost being in the workmanship; it was not ordinarily made in the small sizes which would have been suited to the carrying of the relatively small quantities of nitroglycerine which seem to have been used. Nor was it at all certain that the glycerol would have swelled the wood of the barrel so as to have kept the staves tight in the way that other liquids would. An expensive container usually ensures that a return system comes into being - as with wine barrels. It would have been difficult to ensure that a wooden keg which had held nitroglycerine was entirely empty; a small quantity soaked into the wood or held between the staves would have been extremely dangerous.

The most commonly mentioned container for liquid nitroglycerine is the canister, the 'can'. No definite size or capacity for these cans can be given. Though it seems reasonable to suppose that they would have been of a size to have contained enough explosive for three or four large charges. A litre or a quart of nitroglycerine would have represented a considerable amount of preliminary rock boring. For shipment, the cans were packed in boxes with sawdust or other material. The tinned iron canister will bear some consideration here, for it is thought to have influenced events.

A tinplate canister of the sixties of last century was likely to have been - if anything - a much more durable artifact than a similar container made today. For no more praiseworthy a reason than that it

was not then technically possible to be more economical with materials, both the sheet iron from which the can was made and the coating of pure tin on that plate would have been very much thicker than we are used to see. The fabrication of such canister - the cutting, bending, and edge-lapping - would all have been done by machine. Only the soldering of the parts would have been done by hand. It is in these soldered seams that the great weakness of the tin canister lay.

A soldered union between two faces of metal is one of mere adhesion: solder is analogous to a glue. Under stress or sharp shock, such junctures parted at the solder. Want of a means of forming a union of a strength commensurable with that of the materials being used limited the strength and reliability of the containers to that of their weakest parts. Both welding and 'hard' soldering (brazing) had been in common use for many centuries; but neither could be done on any scale because it was not possible to maintain the high temperatures needed more than temporarily or locally. Welding using bottled oxygen was not available until almost the end of the century.

In ordinary commerce it is necessary to accept a certain percentage of defective cans; in the carrying of nitroglycerine only one slightly broached can could lead to a terrible explosion.

The following short quotation is just one example of many describing the accidents which brought nitroglycerine into disrepute, and in which the cause of the explosion can be attributed directly to defects in the containers used to carry the explosive:

"A parcel of nitroglycerine was delivered at Lord Penrhyn's quarry; one of the cans leaked, the materials spreading over the bottom of the cart; on returning home the cart was blown up..."

The Engineer, 6th March 1869, p.149.

Minor leaks in the soldered cans could be sealed by swilling melted paraffin-wax around the inside of the can. Mowbray is said to have made this a usual practice in the U.S.A.

The Frozen Nitroglycerine Controversy

At a temperature of about 40° Fahrenheit (5°C) nitroglycerine was found to freeze into a mass of needle-like crystals. Since this temperature was likely to be encountered on many winter days in Europe and North America, the property was rather more of a nuisance than otherwise. The more general disadvantages of the relatively high freezing point of nitroglycerine will be discussed presently. But it was discovered that when nitroglycerine was hard frozen it was very difficult to detonate by ordinary methods. There seems never to have been any doubt about the utility of this property in the United States, where Mowbray used cartridges of frozen nitroglycerine extensively. The explosive was carried to the site of use in zinc cases lined with felt; detonation was obtained by interposing a small primer of unfrozen nitroglycerine between the charge and the blasting cap.*

In the United Kingdom, however, there was some controversy about the safety of using nitroglycerine when it was frozen. And, having read the material available, it is hard not to entertain the quite robust suspicion that the scare was started by the gun-cotton interest. At the very least it can be said that even if the misunderstanding was not actually engendered by the gun-cotton interest's most prestigious agent, Professor Abel, then neither did he, in his official position as Chief Chemist to the War Office, hurry to have carried out the simple practical tests which would have immediately resolved the question.

But before Abel took up his position in the controversy some rather

* A Dictionary of Applied Chemistry by T.E. Thorpe, B.Sc. (Vict.), Ph.D. F.R.S. Pub. Longmans, Green and Co., London 1891, p.71.

more gross testimony was given currency. Here is Mr. Perry F. Nursey writing in The Engineer of 6th March 1869 (The Nitro-Glycerine Act was to be passed on the 11th August of that year):

"It should be observed that among other disadvantages, nitro-glycerine freezes at a somewhat high temperature, in which condition mere friction will explode it. A sad illustration of this fact occurred in 1867 at Hirschberg, in Silesia, where nitroglycerine was being used in boring a railway tunnel. The oil was one day found to be frozen, and in this state was delicately handled, and by means of a piece of wood fragments were detached. In the bore-holes the frozen nitroglycerine exploded quite as well as the fluid. One day an overseer attempted to break up a lump of frozen material with a pick, the result was a violent explosion ... Several accidents have also occurred in our own country since the introduction of nitroglycerine ... and many of those who were the first to experiment with it have since given up its use. This material, therefore, worthy of utter condemnation..."

(It should also be observed that Mr. Nursey was so far able to overcome his opposition to nitroglycerine as to become 'Engineer to, and representative in England of' Messrs. Krebs and Co., of Cologne, the manufacturers of Litho-fracteur, a nitroglycerine based explosive in competition with Nobel's dynamite, less than a year later).

Professor Abel placed his own considerable weight into the scale pan when he wrote giving his opinion to Sir John Hay, M.P. on the July 1869:

"... such accidents ... at Newcastle, consequent upon the great readiness with which nitroglycerine freezes (whereby it becomes more sensitive to explosion by concussion or a blow)..."

Abel's letter was afterwards to be an embarrassment to him. He had later to explain his assertions - and to do a little retrospective trimming - to his professional peers in the Institution of Civil Engineers:

"In reference to the letter written by him to Sir John Hay, M.P., in July 1869, and used by that officer in his advocacy of the Nitro-Glycerine Bill, he desired to state that he was ignorant of any intention on Sir John Hay's part to read it to the House. With the knowledge he then possessed he could not have desired to have it modified in any way, had he then known it was to become a public document ... nor was there anything in that letter relating to nitroglycerine, in the unmixed or liquid state, at variance with the statements ... although written after an interval of three years had elapsed - except the statement that nitroglycerine was especially susceptible to explosion when in the frozen condition ... the reasons for the opinion, very generally entertained within the last three years, that solidified nitroglycerine was more dangerous than liquid - an opinion shown to be erroneous. The fact remained, that sad accidents had repeatedly occurred with frozen nitroglycerine, no doubt from especially reckless handling of the material, to which its apparent inertness had probably given rise."

At the same meeting testimony was given from several quarters that frozen nitroglycerine was less susceptible to explosion than had been supposed:

"Now the experiments which the War Office Committee made at his quarries (those of Mr. R.F. France) proved - and it was later so admitted in the paper - that nitroglycerine, in its frozen state, was not so sensitive to concussion or explosion."

The Institution of Civil Engineers (Session 1872-73). Vol. XXXV
(Discussion: Paper No.1342 - "Explosive Agents Applied to Industrial Purposes" (pp.2-36)).

The damage done to the reputation of nitroglycerine persisted, and, indeed, carried over into a time when the use of liquid nitroglycerine had been discontinued in favour of dynamite. The magazine Engineering, as late as September 22nd of 1871 (p.183), still thought it worthwhile to devote a short passage to correcting the misconception:

"It is generally conceived that nitroglycerine, and consequently dynamite, is more dangerous, and more easily exploded when in a frozen state than when liquid. But this conception is erroneous, in as much as it is really difficult to explode it when frozen ... A charge of nitroglycerine became frozen in a hole at a quarry near Bangor, and was fired three times with gunpowder without being exploded. A small cartridge containing about half an ounce (28 gram) of the liquid oil was then inserted in the blast hole on top of the frozen charge, and on being fired, exploded the whole charge, which did its work most effectually ... these facts at once silence any theoretical objections ..."

The ease with which nitroglycerine freezes gave rise on occasion to another inconvenience; this was not so immediately involved with safety but was nevertheless of extreme importance. Sometimes, through efforts to maintain a safely low temperature during the nitration reaction, or, perhaps, for more mundane reasons, a batch of nitroglycerine froze while in preparation. This of course meant that the machinery was out of commission until the nitroglycerine had thawed and become liquid again. Oscar Guttman records in his reminiscences^{*} how a vat of nitroglycerine which had been allowed to freeze took all of two days to thaw out. The loss and the simple inconvenience resulting from such occurrences make it easy to appreciate why there was from the earliest days of manufacture a search for an effective anti-freezing agent which could be added to the nitroglycerine during or after the nitration.

Referring again to Oscar Guttman,^{**} he was to recall:

"I had myself ... worked with Nobel, but found that most additions to nitroglycerine reduced the explosive power considerably when used in such quantities as to be efficient."

(A particular case from the source cited above will be mentioned here because it serves to show how occasionally poor communication can

* and **

Twenty Years Progress in Explosives, Oscar Guttman, Whittaker, London, (1909) (p.23).

result in the effective loss of a technical innovation. In 1866, in Sweden, A.E. Rudberg patented the addition of nitro-benzine to nitro-glycerine for the purposes of reducing its tendency to freeze (Swedish patent of 30th April 1866). Because Swedish was not a widely known language, the patent was little known. Nobel patented the same invention nearly twenty years later (British patent No.5330 of 1885).

Failure to discover an effective means of preventing nitroglycerine from freezing was to lead quite directly to a useful advantage in another direction - the temporary stabilisation of nitroglycerine.

The Newcastle Nitroglycerine Explosion: A Case in Point

The explosion of nitroglycerine which occurred at Newcastle upon Tyne on 17th December 1867 was only one of many such disasters which had happened across the world between 1866 and 1867. All of these explosions were of nitroglycerine in transit, where the liquid was being moved in quantity, rather than when it was actually being used in a blasting operation.

The Newcastle explosion was not by any means the most devastating of the nitroglycerine accidents. However, it did take place in the United Kingdom, in an urban area, and several important local figures met grisly deaths; for this reason the event was given more immediate and more strident publicity than it might otherwise have warranted.

Only those details necessary to illustrate the hazards associated with the use of nitroglycerine will be quoted directly.

Essentially, the story is that nine 'cans' of nitroglycerine, 'for blasting purposes', were discovered to have been abandoned in a cellar in White Swan Yard, off the Cloth Market, in what was then the centre of the city of Newcastle upon Tyne. The police applied to the magistrates and consequently an order was made to have the cans removed.

'Not being able to induce the Railway Company to carry it', it was decided to take the explosive to the Town Moor where it could be poured away into a pit caused by colliery subsidence. The canisters were placed in baskets and loaded onto a cart for carriage to the Town Moor. This was a distance of about two miles, for the most part up more or less steep hills, and probably at that time over unmade tracks for part of the journey. A crowd is reported to have followed the cart.

The 'corks' sealing the cans were removed with a 'pricker'.

'They emptied the liquid of the whole nine(cans) into the subsidence of the earth, and after this was done it was found that three of the canisters still felt weighty. The Sheriff thereupon ordered the men to take off the ends, (of the cans), which being done by means of a shovel(!), when it was found that a portion of the contents had crystallised and was adhering to the tin. The Sheriff expressed a desire to obtain a piece of the crystallised material, and asked for a piece of paper, but what followed is not known.'

Eight men, including the Sheriff and the Town Surveyor, were blown to pieces. The Jury returned the following verdict:

'That death has been caused by the explosion of nitro-glycerine, accidentally; and the jury are unanimously of the opinion that the law in reference to the storing of nitroglycerine has been grossly violated in this case.'

Historical Register of Remarkable Events
(A.D. 1867), Fordyce, Newcastle, 1871

'Phlegmatised' Nitroglycerine

Nobel himself instituted the practice of dissolving nitroglycerine in methyl alcohol - 'wood alcohol', 'wood naptha', 'wood spirit' - before transport. It can be supposed that Nobel had only to make a short inventive leap from his failure to discover a ~~usable~~ anti-freeze for nitroglycerine to a realisation that he had incidentally stumbled across a way of rendering nitroglycerine inexplosive.

The process was easy to reverse: thrown into an excess of cold water the nitroglycerine separated out below the much diluted alcohol where it could easily be tapped off for use.

The operation did render the nitroglycerine safe to transport. Large quantities of the liquid explosive were shipped across the Atlantic from Sweden for the blasting of the Hoosac Tunnel.

The method may not, however, have been used invariably; there is some indication that nitroglycerine was carried in the undissolved state after the introduction of the method. Not all nitroglycerine was made by the Nobel Company.

There were a number of objections to the practice. The alcohol was expensive (though it may have been quite cheap in Sweden where destructive distillation of wood was carried out on a large scale), and the spirit could not easily be recovered when it had been diluted. The larger cans needed to carry the same effective quantity of explosive would have taken up more hold space and thus have attracted a higher rate of freightage. Liquids of low viscosity tend to leak through more minute holes in containers than do liquids of high viscosity. Alcohol vapour leaking from cans would itself give rise to a highly explosive mixture when mixed with air. At low temperatures the nitroglycerine could crystallise out from its solvent.*

The method was discontinued on the grounds that the method of separation was troublesome. Nitroglycerine cannot have been transported in this mode for more than a few years before the practice was almost entirely superceded by the introduction of dynamite.

No material has been found which indicates that nitroglycerine was carried in the United Kingdom in any other way than in its pure, undiluted form.

* A Dictionary of Applied Chemistry, T.E. Thorpe, Vol.II (p.77) , Longmans, Green and Co., London, 1891.

Chemical Analysis of Nitroglycerine

It is proposed not to offer here any discussion of the work which went into the achievement of a true chemical analysis of nitroglycerine. A full and detailed account of the principal studies from Sobrero's discovery in 1846 to the publication of Hay and Orme Masson's analysis in the Transactions of the Royal Society of Edinburgh for 1887 can be found in the already quoted work:

Historical Papers on Modern Explosives by George W. Macdonald, M.Sc.(Melb.) Published by Whittaker & Co., London 1912, Chapters XXIII, XXV and XXVI.

Some Probable Causes of the Early Nitroglycerine Explosions

Valid forensic conclusions cannot well be drawn from documentary evidence alone. Nevertheless, it is proposed to show, firstly, that there was some understanding of the probable causes of the early nitroglycerine disasters; and secondly, that later in the century an additional factor was discovered which, though it was not suspected in the 1860's, presents itself as a factor which almost certainly was operating in the case of the nitroglycerine explosions which then occurred.

Two references only will be used to support the propositions.

The first will be used to show that when nitroglycerine was first made in quantity there was every likelihood that the explosive was contaminated with residual nitric acid.

"Later on, Nobel ascribed the accidents which occurred to the use of the square tin cans, in which the oil was contained, the spring of the tin causing a concussion which brought about the explosion, it not being known at the time how sensitive nitroglycerine is to concussion. It may also be that some of these early accidents were due to spontaneous decomposition as Nobel stated that nitroglycerine being so remarkably indifferent to almost

every chemical substance, it was not known that nitrous and nitric acids form exceptions and that, as they naturally adhere to crude nitroglycerine, they must be washed out carefully. Nobel was, in fact, not sufficiently acquainted with the necessity of thoroughly washing and neutralising his blasting oil.

Journal of the Society of the Chemical Industry
May 31 1899 (p.444)

Quoting

'Nobel's evidence before the Royal Commission on Explosive Substances, 1874.'

The second reference will show that it was later discovered that in the presence of nitric acid the tinplate from which the cans were made may itself have become dangerous.

"NITRATE OF TIN merits a mention as being a possible cause of obscure explosions in powder mills. It was found in Spandau that frequent ignition of the powder took place at a certain stage of its manufacture ... On examining the machinery it was found that where bronze pieces which were soldered were in constant contact with the moist powder, the solder was much corroded, and in part entirely destroyed. In the joints a substance had collected, which when scraped out with a chisel exploded with emission of sparks ... it was found that if a thin layer of sulphur and saltpetre were placed between sheets of tin and copper foil and allowed to remain in a moist condition, after a time the copper was coated with sulphide, and the tin was largely converted into an explosive basic nitrate ... can unite with the tin of the solder to form the explosive basic nitrate, which, being insoluble, gradually collects in the joints and finally leads to an explosion. The substance when obtained is a pure white crystalline powder, which explodes violently with a shower of sparks when heated rapidly or subjected to percussion or subjected to percussion or friction. It is formed when a fine spray of nitric acid (s.g. 1.20) is thrown upon a surface of tin or solder..."

A Dictionary of Explosives by Major J.P. Cundill
R.A., H.M.'s Inspector of Explosives (p.100),
London 1889 Edition

Quoting: Notes on the Literature of Explosives
by Prof. C.E. Munro, U.S.N.A., of the U.S. Naval
Institute, No.III, p.671 et seq.

The tinplate canister, as has already been suggested, may have been the best available container. But, because of the unsuspected contamination of the nitroglycerine it was being used to carry, and the large proportion of tin in the solder used to join the parts of the can, it became inherently dangerous.

In the first instance the residual acid is likely to have rendered the nitroglycerine chemically unstable. It is remarkable that the hard lessons which the earlier work on gun-cotton had taught - the dangers which attended there being the slightest trace of acid in the finished explosive - should not have been heeded when nitroglycerine came to be manufactured.

The action of any residual acid would, however, also have tended to dissolve or greatly to weaken the bond of common solder holding the cans together. This alone may have been the cause of much spilled nitroglycerine. And it was the more dangerous because it was unsuspected.

However, the principal factor which it is wished to introduce here is the formation of nitrate of tin inside the canister.

There is commonly a small excess of solder along a joint. This is most likely to occur along an inner seam which cannot easily be wiped clean. If nitrate of tin crystals were formed they would have been clustered most thickly along the length of the inner parts of the seams, and within the overlap of the metal edges.

Nobel was persuaded that the cause of some of the explosions lay in the 'spring' of the tinplate. This may also have been so. Square canisters without corrugations or braces to strengthen them are not best suited for the carrying of liquids, especially those liquids of high specific gravity. They are used because they allow more economical packing.

Any or all of the above factors may have contributed to the series of apparently spontaneous explosions which occurred between 1862 and 1867.

The detonation of nitrate of tin crystals brought about by the shearing motion along weakened seams between edges of metal represents a complex rather than a simple explanation of a phenomenon. But the conjunction of conditions necessary for this to have happened does seem to have been present.

CHAPTER 7

WYNANTS' POWDER - SAXIFRAGINE

(1862 - 1875)

Before attempting to discuss the barytic blasting powder which was introduced into the United Kingdom at the beginning of 1862 it will be necessary first to clear some ground.

Barium nitrate was used for two distinct purposes in the preparation of explosives. It was for a brief time under serious consideration as a substitute for potassium nitrate in some propellant gunpowders. It was also used as a novel oxidising agent in a patent blasting powder. This is a distinction not always clearly drawn in the printed sources consulted.

A blasting explosive under the name Wynants' Powder was granted a British patent (No.1,084) on 15th April 1862. Thus, so far as the United Kingdom is concerned, the use of barium nitrate as an oxidising agent preceded attempts to apply it to a propellant use by at least three years.

F.A. Abel, writing in 1871,^{*} stated that barytic gunpowder, as he called it, had been intended first to be used as a mining explosive, and that it was later that it was attempted to use it in ordnance. This may describe the sequence of events in this country. But it is observed that Wynants was an artillery officer. It is plausible to suppose that Wynants' work with barium nitrate, on the Continent, began before 1862, and perhaps well before 1862, with researches into its potential as a constituent of cannon powder, and that it was during the course of this work that it occurred to him to find a civilian use for compositions containing barium nitrate.

Abel seems not to have been aware - or perhaps not to have recalled - that there was an essential difference between the respective compositions

* Explosive Agents Applied to Industrial Purposes by F.A. Abel, Proceedings of the Institution of Civil Engineers, 14th May 1872, Volume XLV, p.332.

of Wynants' propellant, poudre barytique and his blasting powder. The powder to which Abel was referring was that which was the subject of the paper, 'On Barytic Gunpowder for Heavy Ordnance', which was read before the 1866 meeting of The British Association for the Advancement of Science by Mr. C. Vignoles, C.E., F.R.S. This paper was reprinted in the journal Engineering for 31st Sept. 1866 (p.150). The essentials of this paper are given in its second paragraph:

"This particular kind of gunpowder has been much experimented upon, both in Belgium and in France, with a view to counteract the injurious effects which are produced when large charges of powder are used in heavy ordnance. The principle upon which this barytic powder is composed is simply that of substituting nitrate of barytes, instead of saltpetre, in the composition of gunpowder, in certain proportions, the consequences being that the powder, when ignited, consumes more slowly, and gases are developed less rapidly, than in ordinary gunpowder while the same effect is produced upon the projectile as regards its ultimate velocity. This lessens the injurious effects upon the sides, vent, and chamber of the piece of artillery."

The above assertion being that barium nitrate was substituted for potassium nitrate is qualified later in the same paper:

".... a barytic compound called 80 per cent, that is to say one in which 80 per cent of the saltpetre was replaced by a quantity chemically equivalent to nitrate of barytes."

Nevertheless, the outstanding difference between the two preparations - the difference which makes one 'a gunpowder' and the other 'an explosive' - is the absence of sulphur in the Wynants' Powder.

The development of the two types of powder diverged. The propellant variety appears not to have gone beyond the experimental stage in the United Kingdom. Abel himself, at the same meeting of the British Association cited above, is quoted as having spoken against the barytic

gunpowder in a way which may well have precluded further official patronage there and then:

"Professor Abel remarked that gunpowder could be made fast burning or slow burning without the use of barytes, which had been found objectionable on account of its fouling properties. The quality of gunpowder can be altered at will by subjecting it to a slightly different treatment in manufacture without its being necessary to add chemical components to it which are otherwise objectionable."

A substitute for potassium nitrate is likely to have received short official shrift in the 1860's. Britain had very large resources of saltpetre in her empire. The commercial interests in Indian earth-saltpetre would have reacted with vigour to any attempts to replace their product. The Trent Case* and the embargo on supplies of nitre to the Federal side in the American Civil War had then recently demonstrated the strength of the British position in this matter very convincingly. And in any event relatively minor improvements in steel-making processes were likely to have obviated the ordnance problem altogether.

A second point of uncertainty resides in the use of two names to refer to what, it seems almost certain, was a single explosive. Wynants' Powder and Saxifragine had identical formulas: 77 parts barium nitrate, 21 parts charcoal, 2 parts saltpetre.

Since the name 'Wynants' Powder' appears to have given way very quickly to that of 'Saxifragine' it may be supposed that 'Wynants' Powder' was what the explosive was called in this country when it had only recently been introduced and was the subject of articles in the various journals. It was only later, it is suggested, when manufacturing and marketing were established, that 'Saxifragine', the name already in

* History of American Technology, by J.W. Oliver, Ronald Press, New York (1956).

use on the Continent, was adopted. The need to force a distinction between the powder which had been introduced by Wynants, the unsuccessful poudre barytique, from the blasting powder which Wynants had patented, can readily be understood.

(Saxifragine is a curious name for an explosive. To the modern reader, to whom if it has any associations at all it suggests wild-flowers, it does not sound a particularly apt one at all. It may of course have been more meaningful to 'classically' educated men of the nineteenth century. Nevertheless, and even at this distance in time, it looks as though Captain Wynants was rather less well grounded in his etymology than he was in his ballistics. Chamber's Dictionary (1910) gives the Latin derivation:

"Saxifraga - saxa, a stone, frangere, to break, or, according to Pliny, from a supposed efficacy in breaking up calculi in the bladder."(!))

Certainly there appears to have been only one British patent for a barium nitrate blasting explosive taken out in 1862.

In Cundill's A Dictionary of Explosives (p.13) there is a heading: 'NEWTON see Saxifragine. The heading SAXIFRAGINE makes no reference to NEWTON. However, NEWTON, 'Vincent Henry Newton of Chancery Lane, London', and 'Newton, William Edward Newton', were both active patent agents, especially concerned with explosive patents, during and after the 1860's.* Both acted for Nobel while that inventor was in Paris during 1863. Indeed it is this information which suggests the following possible explanation. Wynants may have needed to employ one or other of the Newtons to secure his British patent, while he himself was in Europe securing his own interest there. The name 'Newton' on a patent may have been no more than a necessary fiction to gain the protection of British patent law for an alien. It will be recalled that Von Lenk used the name of his friend,

*The 'Provisional Protection' columns of Engineering, The Engineer, Chemical Gazette etc. 1840-1875.

John Revey., when patenting his gun-cotton process in the United Kingdom.

Now, having cleared the ground, there is not a great deal which can be said of Saxifragine. No material has been found which might indicate where it was made, what the process actually was, how successful it was. All that can be said is derived from a very few 'major' and very general sources.

Saxifragine was made in grains. The manufacture was thus very similar to that of common gunpowder. A feature of the very many later alternatives to gunpowder was that they required no great degree of processing, and therefore little expensive plant. Saxifragine could have been made in any existing gunpowder mill on a contract - batch basis.

Both Abel and Cundill mention that it was necessary to dust over the grains of Wynants' Powder, 'while still damp' with mealed black gunpowder. If this was so, then the formula given for the blasting powder is not accurately specified. Assuming that the blasting powder was made in relatively large grains, the addition of a pelicle of mealed powder (and the use of this by no means fine powder may imply that Wynants' Powder was large grained) would add appreciably to the whole, and strictly speaking should have been accounted for in the formulation. But since it was not, Saxifragine might be said to have been a two-stage explosive. When the charge was ignited the black gunpowder grains disseminated throughout - as a separate charge almost - would quickly have flashed through the body of the cartridge, igniting the exposed surface area of the large grains of barium nitrate explosive.

Few special properties which might have commended Saxifragine over black gunpowder are mentioned in the literature. Only F.A. Abel, again in his 1872 paper, gives a brief and disjointed resume of some of its merits:

"In addition to economy, the production of a powder which should act with gradually accumulating force, and which should be applicable as a blasting powder, so supplies placed in the hands of miners would not be diverted to other purposes."

Whether the economy came from a need to use less powder for a given job or whether it was because the ingredients were cheap is uncertain.

Saxifragine contained no sulphur, directly, and this was always the most expensive constituent of black gunpowder. Barium nitrate does not occur in Nature in the sort of concentrations that would have been needed for any extensive use in explosives.

The value of an explosive which exerts a gradually accumulating force can be understood. In the quarrying of large pieces of stone, such as Gateshead Fell sandstone which was used for millstone making, it was particularly important that the stone should not be shattered: a relatively slow 'nudge' easing the block of stone free along its natural jointing was what was needed.

Concern for the misuse of the explosives was growing during the 1860's and 1870's and was to lead to several pieces of legislation, ending in the 1875 Explosives Act which is in force at the present day.

Many references cite the absence of water of crystallisation in the molecular structure of barium nitrate and the fact that it was not in any degree hygroscopic which made it a candidate for use in place of potassium or sodium nitrate in explosives.

Of how long Saxifragine powder was in use, of what measure of popularity it enjoyed, nothing can be offered. References to Saxifragine appear in articles on explosives in technical dictionaries until well into the present century. There is, however, a sameness to them which gives rise to a suspicion that Saxifragine - and perhaps many other compounds - had a much longer life in print than they did in practice.

Why barium nitrate of all the nitrates should have been chosen as a substitute for potassium nitrate was at first difficult even to guess. However, by chance, during the course of general reading an answer was found. Barium nitrate became plentiful because it represented an intermediate stage in the conversion of sodium nitrate (Chile saltpetre) into potassium nitrate. Wagner's 1860 edition of his Chemical Technology (p.139) describes a process first attributed to Longchamp, Anthon and Kuhlman:

"Nitrate of soda is first converted into chloride of barium, nitrate of baryta being formed, and in its turn being converted into nitrate of potassa:-

a. 85 kilos of nitrate of soda		130.5 kilos nitrate of
122 kilos of chloride of barium	<u>yield</u>	baryta and 58.8
		kilos of common salt

And

"... it is profitable to convert native carbonate of baryta into chloride of barium & for instance by exposing witherite to the hydrochloric acid fumes produced in alkali works by the decomposition of salt..."

Barium carbonate was first found and analysed by Dr. William Withering. Mixed with barium sulphate, which had been first suggested by Keir, the salts were used in the making of Wedgwood's jasper ware. Wedgwood himself discovered deposits of barium mineral in Derbyshire.

CHAPTER 8

SCHULTZE POWDER

(1864 - 1878)

Introduction

Schultze Powder should be considered as simply a special development of nitro-cellulose. In the chronology of invention, this 'wood gunpowder' was introduced into the United Kingdom only a matter of months before R.O. Brown was to bring gun-cotton to the virtual optimum of its utility as a blasting agent. It is also remarkable that Schultze powder, coming into use at the time it did, was to find its greatest application where gun-cotton, used alone, had been found to be unsatisfactory - as a propellant.

It had not been intended to introduce any direct treatment of propellants into this study. But it is felt - and it is hoped to show adequately - that the survey would be incomplete without some consideration of Schultze powder. The discussion, however, must be limited to the period 1864 - 1878. The curtailment is a necessary one. The Schultze powder made before about 1878 was essentially different from that which was made afterwards.

Within the progression of discoveries which was to allow the eventual displacement of gunpowder from almost all of its former uses, Schultze powder represents a major branching-off point. Before the introduction of Schultze powder there was no safe and efficient alternative to black powder, for use as a propellant. Schultze powder provided an alternative. Moreover it stood very largely alone in this, at least so far as the British market was concerned, for at least fourteen years. It was to take on a special identity of its own. In this special identity it was to enjoy an extra-ordinarily long period of esteem and use. But this

was not until after 1878.

There is also a sense in which Schultze powder could be said to have been before its time. It was exclusively a propellant for civilian use. Typically, it was the powder used in the shotguns of better-off sportsmen. Sporting reminiscences of the period abound with references to 'Schultze' - it was apparently a solecism to say 'Schultze's'. To emphasise this civilian application of the powder it is necessary to be reminded that the British Army was not issued with 'Cordite' ammunition until the Boer War of 1899-1902; similarly, the American troops sent to fight the Spanish in Cuba, in 1892, used black powder ammunition. Thus some thirty-five years stood between the invention of a smokeless powder and its adoption by the Military. Meanwhile, it was finding a regular and increasing use where its smokeless qualities were least important - in the shooting of driven game.

In the beginning, Schultze is thought to have experimented with mixtures of wood grains and saltpetre, but to have moved quickly to work with the nitrated fibre.*

British patent No.900 of 1864 secured protection for the invention of Edward (Sometimes 'Eduard') Schultze, Captain of Prussian Artillery. A patent was also 'recorded' by an E. Dronke of Oldhall Street, Liverpool, on 24th September 1863: "An improved mode of manufacturing gunpowder suitable for mining and all purposes where....". The communication was from E. Schultze of Potsdam.

Four years, during which time Edward Schultze seems to have worked alone to find financial backing for his invention in this country, lie between the granting of the patent and the setting up of the Schultze Gunpowder Company at Eyeworth, in the New Forest, in 1868.

* Sanford, Nitro-Explosives, 1896, p.173.

The Process of Manufacture

As a process, the manufacture of the wood gunpowder was essentially a simple one; but it was also a remarkably long one, and one which required many distinct operations. Water consumption throughout must have been prodigious.

A most detailed account of the process, adhering, it was acknowledged, closely to the original patent specification, was published in The Engineer for 20th January 1865. However, since this is too long to quote in its entirety, and too repetitive in its style to allow much constructive editing, the whole will be recast in an attempt to provide a clear description of Schultze's process.

Since Schultze drafted his patent specification before he set up his factory in England, it is likely that what he describes in the specification is the existing German factory. He was already well established in Prussia, in Potsdam, before he came to England.

The base material for the making of Schultze powder was wood: poplar, linden, ash, oak. The only distinction made between the various kinds of wood was that it was held that the hard woods - because of their larger and more dense fibres - yielded a more powerful powder, which was thus more suited to blasting.

Production fell into two distinct parts: the chemical and mechanical reduction of the wood to small pellets of more or less free cellulose; the nitration of the cellulose and its combination with nitrates.

It should be said here that exactly what was being done was well understood. This was something more than an empirical process. The following quotation will show the level of understanding:

"With reference to gunpowders made from wood or cotton, it may not be amiss to point out that the fibre of these two substances is chemically identical, and that the products obtained by treating these two bodies respectively with nitric acid of equal strength are likewise undistinguishable one from another. Those manufacturers, therefore, who choose cotton, do so because it affords the purest fibre, and therefore needs least cleaning..."

To obtain the small cubes of wood required, timber was first sawn into a 'veneer' of about 1/16th inch (1.59 mm) thickness. The initial thickness of the veneer was varied according to the size in which it was wished to make the finished powder.

The veneer was passed through a machine which 'punched' out tiny blocks of wood which were as broad across as the veneer was thick. The 'reticulated plates' remaining were then utilised by being sawn into strips and then into small irregular pieces of about the same size as the punched-out pieces.

A hundred pound (45.36 kg.) batch of the wooden blocks was placed in a copper with as much water as would freely float the grains of wood; three pounds (1.36 kg.) of carbonate of soda was added, and the whole set to boil for 'three or four' hours. At the end of this first boiling the freed 'acids and other easily soluble substances' were poured away as a discoloured liquid, the water was changed, and the soda was renewed, and the boiling was continued for a further three or four hours. The 'grains' were then removed and washed for twenty-four hours in 'cold running water'.

After drying, the grains were then treated to remove 'proteins, albumins etc.' by being steamed for fifteen minutes in an iron box with a perforated base. Again the grains were washed for twenty-four hours, and again they were dried.

Bleaching was done with fifteen pounds (6.8 kg.) of chloride of lime dissolved in 260 pints (147.7 litres) of water held in closed vessels.

This operation continued for two hours during which time the grains were stirred. Alternatively, chlorine gas was used: the gas was passed through the dry grains until all trace of their colour was removed. This concluded the first part of the process.

There was of course nothing very much new about this part of the process at all. The making of paper from pulped wood had been in use since 1844, following the discovery made by Keller at Hainichen in Saxony.

Nitration required 'a mixture of 40 parts of nitric acid of specific gravity 1.48 - 1.50 with 100 parts of sulphuric acid of specific gravity 1.84'. Vessels with provision for cooling with cold water were used for the nitration.

Six parts by weight of the grains were stirred into one hundred parts by weight of the acid for 'two or three' hours.

After nitration, the grains were separated from the acid by being spun in a centrifugal machine.

The following quotation from the specification gives some indication of the general availability of quite sophisticated processing machinery at the time:

"As this machine (The Centrifuge) is well known and used in sugar refineries and laundries etc., a description is not deemed necessary."

Removal of residual acid took longer than was usually needed for the treatment of gun-cotton - though the length of time for which the grains were actually boiled was not so protracted. After a final three day long washing in running water, the grains were again boiled in a weak solution of carbonate of soda, washed once again, and again dried.

Treatment of the finished grains with nitrates - potassium nitrate, barium nitrate, or a mixture of both - was also a wet process. The salts were dissolved in boiling water in a proportion near to the

saturation point for the particular salt or mixture of salts being used.

Finally, the powder was dried for eighteen hours at a temperature of between 90 and 112 degrees Fahrenheit ($32^{\circ}\text{C} = 44^{\circ}\text{C}$), and when dry it was passed through screens to remove fine dust.

The dust from the final screening process was wetted with 'gum-water', pressed under strong hydraulic pressure into thin sheets which were again punched out into small uniform pieces. Such powder was considered to be 'best suited for rifled small arms'.

This final reprocessing, which to begin with was perhaps no more than an economy measure, was to become an extremely important factor in the Company's survival and eventual success. Powder made to the ordinary specification was somewhat loose in texture. Powder made by the reprocessing of the waste dust was markedly different. There is no way of knowing exactly what it was like without duplicating the process, but it seems sensible to suggest that the grains of reprocessed Schultze powder were a little smaller, a little more dense, smoother (horn-like, perhaps) than the original powder. Above all, the cellulose of the reprocessed powder was divided into particles so small as to be not at once identifiable as wood fibres at all. This difference was, however, an entirely mechanical one; there was probably very little chemical difference between the two kinds of powder.

It might be said that Schultze powder only became successful when the treatment of the wood fibres had proceeded to a stage of reduction which made them practically indistinguishable from pulped cotton linters.

The Properties of Schultze Powder

The final paragraph of the article in The Engineer cited above gives a list of the special advantages offered by the new powder. These were of course the inventor's claims, and indeed, they were in the long run

made more or less good. The essential points of these claims will be given below. But matured and informed independent opinion, recollecting the performance of Schultze powder during the first twelve to fourteen years of its use in the United Kingdom, expresses reservation, and some dissent. Something of these opinions will also be quoted.

Schultze claimed:

"1st. It has for equal weights from three to four times the strength of gunpowder."

"It can be manufactured at less cost than gunpowder."

"Its explosive effect is more regular than gunpowder, in consequence of the greater uniformity of its grains."

"Its volatile products being chiefly oxygen, the vapour of water, nitrogen, and a small quantity of carbonic acid, are not offensive to the lungs, while those of gunpowder..."

As a process of manufacture, the making of Schultze powder was not quite, as it claimed, entirely safe. However, only one record of an explosion at a Schultze factory has been found in the sources consulted.*

The following comes from an article in The Engineer of 12th February 1868, which article was in turn based upon a paper by a Mr. Dougall which had then recently been read before the Royal United Services Institution: Captain Schultze's New Gunpowder. (The article is headed 'White Gunpowder' which shows that the nomenclature of cellulose explosives had not at that time been fully resolved, at least at the level of the popular and professional journals).

"In Potsdam the police regulations to prevent fires are so stringent that they will not even let a rocket be fired off, yet the manufacture of the new powder is considered so harmless that they let Captain Schultze make it in the back garden of his private residence, the works being only forty five feet from his house. The chief assistant is also in the habit of smoking his pipe inside the works."

* Irish Universities Press Series of British Parliamentary Papers. Report on the circumstances attending an explosion at the factory of the Schultze Gunpowder Company (Limited) at Eyeworth, Hampshire, on 8th August 1877; (c.1911) XXI. 709.

The editor of the magazine The Field recorded his own impressions of Schulze powder as it had been from its introduction until 1878, when he himself instituted some systematic trials of the powder. This gives a more balanced picture of Schultze powder:

"After a time a company was formed in England, with Colonel Gompertz as its promoter, and works in Hampshire, to carry out the Schultze patent; and their powder was an improvement on the original in point of form, being composed of comparatively regular granules, instead of the fibrous ones which resulted from the first process. The improvement in its manufacture at Ringwood (The second factory) were regular and gradual, as generally happens, the chemist in charge of the works (Mr. Griffiths), though well skilled in his own department, had no knowledge of the sportsmen's requirements, and neither he nor Colonel Gompertz was able to examine the powder, when made, from a sportsman's point of view ... But about the year 1878 its quality so improved ... that I determined to institute a competitive trial of it in comparison with the black powder ... The Trial came off at Wimbledon in May 1878."

The Modern Sportsman's Gun and Rifle
by J.H. Walsh ('Stonehenge'), published
Horace Cox, "The Field" Office 346,
Strand, W.C. 1882, Chapter X (p.298).

'Stonehenge' was extremely thorough in his examination of Schultze powder. He went so far as to commission a chemist to carry out an analysis. The chemist's report on Schultze powder gives us the closest view of the composition it was possible to give for the level of analysis available at the time:

"... Schultze powder, in its early days, was made from wood fibre in a condition resembling a mixture of sawdust and shreds or splinters, for which roughly cut cubes were afterwards substituted. This would be a cheap material, but on account of the large amount of gummy and other impurities that have to be removed, it requires even greater care than is requisite with cotton ... the granulated Schultze powder now produced appears to be made from pulped wood fibre, partially converted into 'gun-cotton' ... then mixed with nitre ... and consequently consolidated into grains by pressure ...

Where accidents have occurred with any such powders it has generally been traced to a desire to quicken the rate of combustion (which is surely quite unnecessary) by increasing the percentage of more highly explosive substances. In the sample of Schultze that caused several accidents in 1878 I

found that one half of the wood fibres had been converted into gun-cotton ... whereas in the ordinary samples only about one third of the wood fibre is so converted...

F. Woodland Toms F.C.S.,
7 Busby Place, N.W., 5th October 1882

Letter to J.H. Walsh
Published in:

The Modern Sportsman's Gun and Rifle
by J.H. Walsh ('Stonehenge') Published
Horace Cox, "The Field", Office 346
Strand, W.C. 1882 (p.326).

Other Uses of Schultze Powder

Aside from his propellant powder, Schultze also offered a blasting powder. Little information regarding this branch of his work is recorded in the literature. It may be that in the early years after he had invented his powder Schultze was not entirely sure of the most suitable application for it. In the United Services Paper cited above, Dougall makes the statement:

"Captain Schultze is now making seven different kinds of his powder, each adapted to its own particular purpose."

Certainly the powder could be used as an explosive. Dougall reports having witnessed a demonstration of its use under water; though it should be said that the charge used was minute.

Schultze blasting powder was much the same as his propellant powder except that an unspecified percentage of charcoal was added. Cundill, in his dictionary, gives formulae for two powders made by Schultze which contain such extra constituents as 10 per cent of sulphur, and very small percentages of paraffine and 'nitro-tar'. These formulae, however, almost certainly come from a later date: Cundill describes both as 'Authorised' explosives.

The Place of Schultze Powder

It has been easy to place Schultze powder within a classification of the explosive substances which were discovered and developed during the nineteenth century. It was a form of nitro-cellulose which differed from the main progression of development only in the use of a slightly unusual raw material.

The reason for this choice of raw material came about almost certainly because the inventor came from Prussia where wood-pulp was more plentiful than cotton linters, and where, it should be said, at that time there was a more ready appreciation of the fact that wood-pulp and cotton were essentially the same thing. Schultze powder might well be considered as an early example of an ersatz manufacture.

Additional Observations

It was particularly fortunate for Schultze, and for the continued development of his powder, that he made his discovery at the time he did, for it looks to have depended crucially for its successful application upon several other inventions which were introduced only a little time before and a little time after he opened his United Kingdom factory.

As it is described in its original form, the powder almost certainly required the use of a breech-loading gun. It would have been wasteful and difficult to charge a muzzle-loading gun with so light and flock-like a powder, especially if there were any breeze blowing. And, again, the use of a ramrod would have produced just those differences in the packing of the charge which were later to be the cause of such wide variations in the powder's performance.

The first truly safe and efficient breech-loading shotgun was brought out by the London gun-maker Daw in 1861. The self-contained cartridge upon which the breech-loading shotgun depended for its

efficiency and safety had been invented by Lancaster in 1851; Pottet patented what was essentially the modern shotgun cartridge in 1860.

None of the above would have enjoyed any extensive use without an increase in the sheer numbers of breech-loading shotguns which advances in machine tools made possible. Daw's shotgun cost fifty guineas in 1861; Lang was able to sell a 'plain' gun for twenty pounds in 1865; it was not until 1874 that Bland was able to offer a 'keeper's gun', one that was devoid of all decoration but which was essentially a quality weapon, at six guineas. The costs can, of course, only be reckoned as relative to each other. The wage for a town labourer at the time was about a guinea a week; the cost of the Daw gun would, therefore, have been seen as extremely expensive by most people; while the Bland gun might have been comfortably within the reach of a tradesman in a modest way of business.

The impetus for the popularity of the sort of field sports which required the expenditure of vast quantities of ammunition cannot be discussed here. However, it can be remarked that this fondness for shooting rose to such a height that at one point (1880) the London gunsmiths were to complain about the legal limits imposed upon the quantity of Schultze powder they were allowed to keep on their premises.

Something might be said here of the commercial imperatives which faced the Schultze Gunpowder Company. From a costs=profits point of view it was necessary that the firm specialise early in a powder for cartridges. The technological niche which Schultze was to fit for so long was determined by the most useful properties the powder could offer.

Now, a hundred pound batch of finished Schultze powder would make up into about 14,000 finished cartridges:

$$\frac{7,000 \text{ grains} \times 100}{50 \text{ grains}} = 14,000$$

- a. (1 grain = .0648 gram)
- b. (Seven thousand grains equal one pound; fifty grains was an ordinary full charge for a 12 bore shotgun. Modern Shotguns, Greener, 2nd Edn. 1891, facsimile Edn.)

The same hundred pound batch of powder would make up into only four hundred four-ounce (114 grams) blasting cartridges. The trade in blasting explosives was at that time extremely competitive.

Schultze powder, used as a propellant, had few serious competitors - save black gunpowder - for at least twelve years after its introduction. What might have been a formidable competitor, Prentice's Gun-cotton powder, was abruptly removed when the Stowmarket factory was destroyed by the explosion of 1871.

Edward Schultze wrote a book:

"The New Chemical Gunpowder (Sawdust-powder), and its advantages over Black Gunpowder and its Substitutes,"
by Captain E. Schultze, published Asher and Co., 1865.

It has not been possible to find a copy of this work.

The information that all of the staff - not the workers - at the British Schultze factories were interned in 1914 allows us to conclude that the connection with Germany remained strong.

An Additional Note

The Philosophical Magazine for March of 1847, during the course of a paper, XLIII. On Gun-Cotton by E.F. Tesclemacher, p.261, contains the following:

"Many other vegetable fibres may be substituted for cotton ... it appears they do not possess the explosive force of cotton. In a trial upon flax, I found 50 grs. increased in weight to 72 grs; the explosive force was feeble; this was the case with sawdust similarly prepared; but it is possible that this form of impure lignin may eventually be more important than it appears at present..."

E.F. Tesclemacher had prepared what he called 'gun-sawdust' as early as 2nd November of 1846.

CHAPTER 9
NEUMEYER'S GUNPOWDER
(1865 - 1869)

This explosive was a true gunpowder. The constituents were much the same as those used in common black gunpowder; the proportions of those constituents were not significantly different from those ordinarily used.

The powder was invented by Gustave Adolf Neumeyer, described as a 'quarry manager and owner, of Tauch in Saxony'. Whether Neumeyer attempted to promote his invention first on the Continent, or whether he aimed directly at a British market, is not known. The invention was secured in the United Kingdom by two patents. The first, British patent No. 1,636, was registered on 17th June 1865; the second, British patent No. 1,408, was registered on 13th May 1867.

Cundill gives the following very ordinary formula for Neumeyer's Gunpowder:

Saltpetre 75 parts
Charcoal 18.75 parts
Flowers of Sulphur 6.25 parts

The first patent specified that birchwood charcoal which had been steeped in soda-lye should be used. This requirement was discontinued in the second patent. The purpose of the soda-lye was to suppress the flammability of the charcoal. Neumeyer had had at least one attempt at patenting such a charcoal on its own. The submission occurs in the 'Not Proceeded With' columns of the English Mechanic for May 1864.

The use of the flowers of sulphur was unusual. This form of sulphur was considered unsuitable for use in powders because of the sulphurous acids it contained. However, flowers of sulphur had the advantage of being already in a finely divided state. Also flowers of

sulphur, which was beginning to be produced in quantity as a by-product from a number of industrial sources in the later 1860's, may have been very much cheaper than the imported rock sulphur preferred by the powder makers.

A short entry in Cundill's dictionary provides all the information which has been found on the process of manufacture. The ingredients were wetted with forty per cent of water - presumably of their weight, for otherwise the mixture would have been a slurry - and then well incorporated by being milled for fifteen minutes in a drum fitted with revolving arms. The mixture was ready for use as soon as it had been dried. Some artificial method of drying must be guessed at; for if such a wet mixture were allowed to dry out gradually, some of the saltpetre would have tended to effloresce out as pure crystals.

The list of the properties claimed for the new gunpowder was fulsome. There was the usual earnest prediction that gunpowder of the ordinary kind would be entirely superseded, at least in mining operations.

"Safety from explosion as long as in contact with the atmosphere, which renders it fit for fabrication, and conveyance; 2, much less smoke; 3, leaving less residue; 4, giving less recoil; 5, its strength will not be diminished by wet or a damp atmosphere: on being redried it will contain the same destructive powders; 6, in commercial value it is much cheaper than other powders."

Neumeyer's Patent Specification, quoted
from The Engineer, 21st December 1866.

The powder was meant to be used exclusively in mining cartridges, where it would have exploded readily when under strong confinement in a shot hole.

Like Gale, who was active at about the same time, Neumeyer offered the public a 'safety' gunpowder:

"The term 'inexplosive' may safely be applied, in as much as there is no possibility of its exploding, either during its manufacture, storage, or manipulation. Not until the proper moment of ignition, when it is well rammed home, is its energy developed ..."

A promotional exhibition was staged in the grounds of the Crystal Palace during December of 1866. (The day was the Saturday before the 21st December, so it was the 15th: The Engineer of 21st December 1866 opens an article on the demonstration with the words 'On Saturday last...'). The centrepiece of the show was a miniature house, some five feet (152.4 cm) square, 'and having two chimneys made of five inch (12.7 cm) drainpipe...'

"Thirty five pounds of Neumeyer's powder was placed inside the house and ignited. An immense body of flame issued through the openings in the roof, but the powder simply burnt, and moved neither brick nor slate! Three pounds of ordinary gunpowder under the same conditions blew the little house apart."

This was sheer showmanship. The house offered about one hundred and twenty five cubic feet (3540.24 litres), in which the gases from the burning powder could expand. The provision of the two five inch drainpipes used as 'chimneys' verged on the fraudulent. The area of the two five inch circles was equivalent to a hole some 6.25 x 6.25 inches square (15.9 cm. x 15.9 cm). This was a considerable - and in the event a sufficient - safety factor. The whole performance depended upon the slow burning nature of Neumeyer's powder. The three pounds of common gunpowder blew the house apart in such fine fashion simply because it burned so very much more quickly.

The wonder is that serious credence was given to this invention at all. There must have been many who saw through the Crystal Palace demonstration.

The patents themselves were fragile. It could hardly have escaped anyone familiar with powder and blasting that ordinary blasting gunpowder could be wetted and well mixed to dissolve the granulation to make a very

similar powder. The loss of the flowers of sulphur would have made little difference. Since damp was the most common source of deterioration in gunpowder, any spoiled gunpowder could have been disposed of in this way.

Neumeyer was fortunate in the publicity he received for his invention. The Engineer of 11th February 1869 contains a well-informed article, one of a series, Explosive Compounds for Engineering Purposes by Mr. Perry Nursey.

It is particularly to be noted that fully two years after the introduction of Neumeyer's invention the article is unreservedly favourable. Within his long article Nursey devotes more than two thousand =five hundred words to Neumeyer's Powder. Rather more than a third of the coverage is taken up by a synopsis of the locations of the trials of the explosive and rather precise details of the form the experimental blasts took.

The powder was demonstrated widely = principally in the Welsh slate quarrying areas. Though at Markfields Quarries in Leicester it is reported to have been successfully used with granite.

Nursey reports on the properties of Neumeyer's explosive in a way which is reminiscent of the phrasing of a Victorian conundrum:

"... bulk for bulk, Neumeyer's powder, when well tamped, is equally as strong, if not stronger, than ordinary powder; whilst weight for weight, Neumeyer's powder is the stronger of the two. In point of weight, the new powder is one sixth lighter than the old..."

It is remarkable there was no great protest that Neumeyer's Gunpowder was nothing more than an unpressed, wet-mixed, ill-incorporated composition, a virtual firework mixture, of a kind akin to the crude gunpowders of the late Middle Ages.

G.A. Neumeyer looks to have spent much enterprise and effort, and this at a time when the development of explosives was accelerating and

expanding, in fostering a technological regression.

Yet, in practical terms, Neumeyer was able to turn to account the plain inefficiency inherent in a powder that was made from low-grade materials and crudely processed. For this reason more than any other, the 'invention' deserves its short mention.

The last reference found which deals with Neumeyer's Gunpowder occurs in the Journal Engineering for 29th April 1871. The article is entitled 'Explosive Substances' and is a very close paraphrase of the article by Nursey cited above. However, it ends with the additional information:

".... but notwithstanding all this, and although of so promising a character, all endeavours to render it a commercial success in England failed, however we believe it still continues to be manufactured and used, M. Neumeyer having erected large mills with steam power at Attenburg and two other places in Germany about five or six years since."

The final sentence in the paragraph presents a contradiction:

"This material is worthy of notice as being the only explosive in the condition of grained powder which has proved superior to gunpowder for blasting; which can be used for fire-arms; which really embodies comparative safety coupled with greater energy than ordinary gunpowder."

As was seen, one of the main characteristics of the powder invented by Neumeyer was that it particularly was not granulated. All that can be suggested by way of explanation for the above is that Neumeyer returned to Germany and set up as a manufacturer of a conventional but cheap gunpowder; or, that he again took up an old practice and was manufacturing a kind of 'serpentine' gunpowder, where the passing of slightly damp powder through sieves gave rise to a loosely granular form.

CHAPTER 10

GALE'S PROTECTED GUNPOWDER

(1865 - 1866)

The story of Gale's Protected Gunpowder exemplifies a technological cul-de-sac: a dead end down a very short lane. But it does serve to give an insight into the human side of the progress of explosives during the period.

Almost nowhere in the course of this study has there been revealed more than a trace of the subjective, the humanly frail side of the men who worked to take the science and technology of explosives from a folklore surrounding a primitive mixture to a coherent body of theory and a great array of complex chemical compounds in the course of only fifty or so years. Beyond an occasional flicker of professional pique, or a slight damning by faint praise, both only to be detected by a certain asperity in the prose style of their professional publications, the chief actors in the story of modern explosives are seldom known by anything else but the accounts of their work. Characters other than principals receive scarce a mention. There must surely have been many hundreds of 'second chemists' and 'intelligent foremen' who made significant contributions. In the case of Gale's Protected Gunpowder, however, there are personalities.

The manufacture and sale of explosives is a business like any other. In the nineteenth century it was perhaps much more like any other business than the present day explosives industry. Gunpowder, common black gunpowder, as a stable and uniform product, was, in the mid-sixties of last century, still the most commonly used explosive substance. There was a large market for it. The main objection to gunpowder was that it was so easily flashed off. The two quotations

given below are typical of dozens - perhaps hundreds - that could be culled from local newspapers of the time.

"January 28 - An explosion took place in the shop of Mr. Stout, King Street, South Shields, which set fire to the premises and did considerable damage. It seems his apprentice was alone in the shop, and had by some accident set fire to a five pound canister of gunpowder. The boy was very much burnt.

"September 10 - An accident occurred this evening, in the shop of Messrs. Turnbull and Co., saddlers and ironmongers, in the Bigg Market, Newcastle. A little boy was playing with an unloaded gun, when a spark from a flint fell into a drawer containing gunpowder and exploded it, blowing out the windows with some force, and dashing every square to atoms..."

Fordyce: Remarkable Events
1838 Local Record
Newcastle upon Tyne

Gunpowder was retailed by grocers in country districts for use in sporting guns; in mining areas it was sold across the counter in paper pokes. It was kept in the home, where it was even used on occasion for blowing the soot from flues and the backs of ovens.

With a commodity of so wide a use and such dangerous qualities, it is easy to see how any idea which could render gunpowder 'safe' would attract attention and investment. And so it was. Gale's Protected Gunpowder came close to being - if only for a short time - a minor 'mania'; it also narrowly avoided being a commercial 'bubble'. The whole business from beginning to end was conducted with a certain passion.

It has been thought more appropriate to the material to be treated here to write a narrative of the events surrounding Gale's attempts to float a company to make and sell his 'Protected Gunpowder'. The narrative will be pieced together from a rather few - few but for the most part very long - articles found in contemporary professional journals. The original articles were not themselves made up from whole cloth but rather were taken from newspaper accounts and published scientific

papers. It should be said, however, that where there is cross-corroboration of statement there has been detected no outstanding conflict.

The first public announcement of James Gale's invention was made in the Plymouth newspaper, Western Morning News of 21st June 1865. Mr. Gale, described as 'an electrician' was said to have discovered a means by which gunpowder could be made non-explosive 'in five minutes, and restored quickly to its original condition'.

A patent ('petition recorded' only) was taken out on the 22nd June 1865 in the name of James Gale, Jun. of Devonshire Terrace, Plymouth; British patent number 1679. The title of the patent was unrevealing: "Improvements in Treating Gunpowder".

The proprietor of the Western Morning News, Mr. Sanders, looks - from the very outset of the enterprise - to have been a principal promoter, an impresario almost, of Gale's invention.

On the 27th June 1865, almost certainly through the offices of Mr. Sanders, a series of experiments was carried out at 'the Government House', Mount Wise, Plymouth, before a party which included Viscount Templetown, C.B., Major General commanding the Western District.

The experiments consisted mainly in applying burning slow matches and red hot irons to vessels filled with gunpowder which had been admixed with progressively increasing proportions of 'Gale's non-combustible powder'; 'the composition of which is preserved as a secret'.

The proportions of supressant to gunpowder used were respectively 1:1, 1:2, 1:3, 1:4. In general, it was found that only those grains of gunpowder which came into direct contact with the slow match or the hot iron were ignited. The loss of powder was negligible.

Gale pointed out to the spectators that gunpowder treated with his non-combusing powder could be moved and stood anywhere at all, and that

consequently there would be no need to build expensive magazines for safe storage.

A report of the Mount Wise experiments was published in the Magazine Engineering on 30th June 1865. This was only three days after the article in the Western Morning News. This was a remarkable speed of dissemination for the times. It could of course be that the experiments were covered by a reporter from Engineering because this had been pre-arranged by the newspaper owner, Sanders. Nevertheless, Engineering expressed some hard-headed reservations:

"The principle involved is very simple, whether it is really valuable remains to be seen"; and "... for all we can see, bone dust would answer the purpose equally well..."

This mention of bone dust among the many inert materials which might have come to mind could hardly have been a chance selection, as will be seen.

Of equal importance was the observation that there had been present at Mount Wise some 'naval gentlemen' who had pointed out that gunpowder treated by Gale's method would be two or more times heavier than untreated powder. The implications of this fact would be immediately apparent to men concerned with the stowage and handling of gunpowder at sea. The Royal Navy was, thereafter, not seen as a potential user.

It is after the Plymouth promotion that the name of Mr. Rendle appears. It is hard to determine with any sureness whether Rendle was himself a company promoter, or whether he was merely an investor looking for a profitable venture. Probably he was a major shareholder who quickly became disenchanted with the scheme and who consequently became the leader of the disaffected shareholders who eventually were to force the directors into winding up the company. However, in the beginning at least, Rendle was enthusiastic.

The account of the demonstration at Mount Wise moved Mr. Rendle to write to James Gale. The letter was answered by Sanders. Mr. Rendle went to Plymouth himself.

The prospectus was glowing. Sanders predicted that the invention 'would bring in £150,000'.

From Rendle's later account of this interview we may glean an insight into the personality of James Gale.

"Mr. Gale said it was worth £1,000,000, and he would not take that unless the Queen would knight him..."

This report may of course represent the spleen venting of an angry loser. Gale may have been in a jocular mood at the time. But equally it might indicate a certain flamboyance of personality of the Victorian type exemplified by P.T. Barnum and George Sanger.

Some agreement must have been reached at Plymouth, for Rendle was impressed enough, and apparently sufficiently well connected, to introduce the invention to some highly placed people: the lords Soho and Bury, the Honourable Arthur Kinnaird.

Further demonstrations were given. One was at Wimbledon. At another - not located - a demonstration of the protected gunpowder's stability was given before H.R.H. the Duke of Cambridge. The Duke of Cambridge was Commander-in-Chief of the British Army. There could hardly have been more significant notice.

A demonstration given at Westminster on the 2nd August 1865 was reported in the Illustrated London News of the 12th August. Perhaps because it had been seen by the Duke of Cambridge, a Gale demonstration was now considered important enough to warrant a steel engraved illustration: 'our illustration gives a fair notion of the scene'.

The form of a demonstration of the protected gunpowder looks to have taken on a set pattern. This was no 'raree show' however. The

spectators were invariably 'gentlemen of scientific and practical reputation' . The Westminster demonstration attracted two knights and an admiral. The materials needed were simple enough:

"A strong fire contained in a temporary stove of piled up bricks, and a large wooden table to support the materials to be experimented with, formed the only appliances requisite, except for some slow matches, fuses, and a red hot poker..."

Unlike earlier demonstrations, however, the spectators at Westminster were allowed to know of just what exactly the secret supressant medium consisted:

"Mr. Gale, in the first instance, exhibited his own powder, which on former occasions was spoken of in general terms as the protective mixture, but, having been patented, is now declared to be simply glass ground as fine as possible."

With the true - and not very exotic - nature of the protecting medium now common knowledge, and the realisation, no doubt, that the original patent was easily circumvented, it was considered prudent to take out a second patent. It was on the second patent that the Protected Gunpowder Company was formed. The patent, again in the name of Gale, was taken out on the 25th August 1865.

The specification of British patent No.2057 was to prove to be an unfortunate one for the enterprise. In widening the specification to take in as many as possible of the readily available inert materials, attention must surely have been drawn to just how many of these materials would serve as well as glass powder. The specification heading read:

"Improvements in the preparing and treating of gunpowder in order to render the same unexplosive, and to protect it from the damp."

If the last clause in the specification was an afterthought, it was ill-considered - as will presently be shown. But more serious was the mention of bone-products in the body of the specification:

"Various dry materials in a state of very fine powder may thus be used, but it is proposed to employ ivory or bone black..."

It was later revealed, by Mr. Rendle at the final meeting of the shareholders, that the directors had proceeded with the floating of the company even though they had counsel's opinion that 'the second specification was already thrown on one side', and that, 'the patent now hung on the slender thread of ivory or bone-black.'

It did not escape all of the investors that ivory black, or indeed the cheaper bone-black, would have been difficult to come by in the quantities needed. Nor indeed was powdered glass either so readily available or so cheap as had been predicted. It may have been this knowledge that gave the investors their first serious pause.

Originally it had been proposed - or rather claimed - that it would be possible to buy-in the glass powder for ten shillings per ton (1.016 tonne) and to sell it at thirty shillings per ton. It is here that the solid gold ingot quality of the tale forces itself upon the attention. The envisaged annual sale was twenty thousand tons (19.685 tonnes). This would represent a profit of £20,000. Not all of the shareholders accepted the vaulting predictions of profits without first taking advice.

A Sir John Hay, M.P., undertook some private enquiries. Among others he approached the firm of Messrs. Easton and Amos, who directed him to 'a large manufacturer of glass flour'. A more realistic price for glass powder was found to be five pounds per ton. Such a price for the main material would naturally reduce the margin of profit, and perhaps even the viability of the whole venture.

When Sir John Hay wrote to Gale and Sanders to acquaint them with this serious disparity between prospectus and reality he received no reply. He reported the matter to the Stock Exchange Committee. On the strength of Sir John Hay's information the Stock Exchange Committee

agreed to delay settling day on the company's stock for two weeks. This last piece of information allows us to make an assumption about the company's financial state. In part or whole the company's capital, at least up to the end of 1865, was subscribed - it had not actually been paid by the shareholders.

How Messrs. Gale, Sanders, et al, overcame their liquidity problem cannot here be stated. It can only be assumed that some way was found, for the company was still making ambitious plans for the erection of factory and plant in the April of 1866. In the meanwhile, however, adverse publicity was to come from another source.

The first of the two most determined detractors of the Protected Gunpowder Company's prospectus was Lieutenant Colonel J.S.G. Ryley.

It takes only a modest insight into human nature to conclude that the motivation for Ryley publishing the bitter attacks he did was rooted in a feeling of chagrin that he had failed to make anything of an invention which shortly afterwards, if only for a little while, looked as though it might make its civilian promoters rich.

Ryley's attack was not upon the invention itself; rather it was upon the military establishment and the director of the Protected Gunpowder Company. He was a disappointed man.

"My great desire was to give the Government the full advantage of my invention without the restriction of a patent..."

It can be suggested, without malice towards the shade of Colonel Ryley, that he hoped for some preferment or a promotion to come of his invention, rather than for commercial success.

The retired soldier was well able to publicise his cause and his grievance. A paper which he read before the Royal Scottish Society of Arts was considered interesting enough, or sensational enough, to be

printed in its entirety in the Practical Mechanics' Journal of the 1st January 1866 (page 316).

In its essentials, and with much of the reference to philanthropy and patriotism excised, Ryley's paper makes the claim that he himself devised a process which was virtually identical to that patented by Gale, 'before I left India in 1855'. His claim would appear to have been justified. He states his principle:

"The principle of my invention - the whole merit of which is comprised in filling the interstices of the gunpowder, and thus thoroughly isolating the grains with a non-combustible medium."

The only significant difference between the two processes was that the material adopted by Ryley was, in the first instance, bone meal, and later bone-flour; then, 'the presence of gelatine being objected to', he settled on bone ash. Thus Ryley anticipated Gale not only in the principle involved but in the material chosen, at least so far as the patent specification was framed. And Gale did hold a patent for his discovery.

Ryley's own attempts to canvas his discovery contrast sharply with Sanders' promotion of Gale's. Though Ryley, in his own more modest way, looks to have been busy enough:

"I communicated my discovery to many of my friends upward of a year ago (late 1864) ... Dr. C.W. Eddy ... Dr. Stevenson Macadam, Edinburgh ... I requested my friend, Dr. Eddy, to communicate the particulars of my invention to the authorities at Woolwich..."

The need for an officer of Ryley's rank to have civilian intermediaries act for him in his approaches to a department of the War Office can only be guessed at. A best guess is that since Ryley was serving in India before 1856 he may have been an officer of the Honourable

East India Company's forces, and as such he would not have enjoyed the same status as a serving British Officer of the same rank.

Ryley did not leave everything to his civilian friends:

"In order still further to ensure that sufficient attention be paid to my invention I forwarded a letter on 16th December 1864 to Captain the Hon. G. Wrottersly, Secretary, Magazine Committee..."

The object of the apparently Byzantine, but perhaps at that time necessary, machinations carried out by Ryley was to gain the favourable attention of, first, General Lefroy, President of the Ordnance Select Committee, and, secondly, of General Sir John Burgoyne, President of the Magazine Committee. Clearly the Magazine Committee would have been the largest of users had the process been adopted.

The middle part of Ryley's paper concerns his experiments with bone-ash admixed with gunpowder. Since his methods and his findings agree to a large extent with those of Gale, treatment of this material will be omitted.

Colonel Ryley's invention was rejected. In a communication of the 16th January 1865, General St. George, Director of Ordnance, informed Lieutenant Colonel Ryley that his method 'had been duly considered but that it was not found to possess sufficient advantage to warrant its adoption.' The decision had been swift: a little over nine weeks from submission to rejection.

It may be that Ryley's approach had been considered importunate. But he had good reason to be bitter and angry when he learned of the consideration given to Gale's process:

"I was thus led to believe that the authorities at the War Office did not look with favour on this or any similar plan ... I was scarcely prepared to find that eight months subsequently, when a similar process was submitted by Mr. Gale ... it was considered novel and efficacious ... admiration of the Secretary of State for War ... who witnessed it at Wimbledon ... the leading journals ... noticed the exhibition ... an invention of the highest importance ... witnessed and praised by Royalty." (Presumably, H.R.H. the Duke of Cambridge).

The tirade takes up fully fourteen lines of wide column printing in the journal; close to two hundred words are devoted to accusations of English official perfidy. The Edinburgh audience, sitting that November night in the George Street Hall of the Royal Scottish Society of Arts (it was only the second meeting of that society), may well have thought it was getting its subscription's worth.

Ryley wrote again to the War Office on the 7th October 1865. But the answer to what Ryley had called his 'reasonable request' gave him little comfort.

"I wrote again ... claiming priority; but was surprised to find that instead of the Secretary of State for War complying with ..., that he altogether evaded it by directing me to be informed in reply that, 'neither the plan proposed by me nor that brought forward by Mr. Gale ... possessed any novelty, experiments having been made for testing the value of similar proposals in the year 1848'."

To be fair on the authorities it should be said that the Secretary of State for War wrote again to Ryley during December of 1865 (that is to say between the date of the Edinburgh paper and its publication in Mechanic's Journal). This time, for whatever reason, it was allowed Ryley had priority:

"I am directed by the Secretary of State for War to acquaint you that you are correct in supposing that you were some months in anticipation of Mr. Gale in submitting proposals for rendering gunpowder non-explosive, in this department."

It may be that this was all that Ryley wanted. But it is probable that his importuning may have irritated the Military Establishment into some serious consideration of what it was, after all, that was being offered by the Protected Gunpowder Company. As it was, the Edinburgh paper was to be often quoted when concern about the commercial viability of Gale's process grew. Nothing more is heard of J.S.G. Ryley after January 1866.

Meanwhile the Protected Gunpowder Company's directors must have overcome their cash problem. The magazine, Engineering, for the 13th April 1866 records:

"Gale's Protected Gunpowder - Extensive works are to be established at Woolwich for the preparation of glass dust, to be mixed with gunpowder according to Mr. Gale's mode of protection. These works will be planned by Mr. C.W. Siemens. Sand will be brought in from the neighbourhood of Woolwich, it will be fused in a regenerative furnace and the crude glass run into water. The glass will then be pulverised in revolving horizontal cylinders, within each a few cannon balls will be placed, and left to roll about; the grist, if we may so term it, will be assorted into different degrees of fineness by being placed upon a horizontal disc in rapid revolution, the centrifugal force throwing glass particles according to their size, into a series of concentric receptacles surrounding the disc and placed slightly below it."

Whether it was also intended that this same machine might also be used to separate gunpowder from glass-powder is uncertain. The introduction to the article quoted above suggest that this may have been considered:

"Mr. Gale's mode ... mixing three or four times its weight of glass powder ... the difference in specific gravity ... readily separates..."

One of the principal objections to the use of the process was, as will be shown, the difficulty in separating the two powders either quickly or completely. Most accounts refer to the slowness and incompleteness encountered in sieving the powder free.

Gale's gunpowder, in spite of the hard adverse publicity the project was beginning to attract was still able to put on a large promotional exhibition. The most grand, in scale at least, was the series of experiments which took place on 20th June 1866. The event was

reported in The Illustrated London News of 30th June 1866.

It is particularly worthy of note that the experiment took place 'by direction of the Ordnance Select Committee'; and, 'Nearly all members of the Ordnance Select Committee were present ...' The costs, the barrels of gunpowder and the damage to an obsolete Government building, could hardly have been great. Nevertheless, they were more than notional and indicate a degree of War Office interest.

No.37 Martello Tower, near Hastings, was the chosen site. Five tons (4.9 tonnes) of gunpowder - in the 'protected' state - was stowed in the tower; one hundred barrels in the ground floor magazine, two hundred and fifty barrels on the timber floor above. The tonnage in pounds, divided by the number of barrels, indicates that each barrel of protected powder contained only thirty two pounds (14.5 kg). This, it is suggested, represents something of a hedged bet on the part of Gale. By using powder contained in the smaller barrels a very great deal of good oak barrel staving was being interposed between the separate charges of powder.

The attempted initiation of the gunpowder was done, by battery and three separate fuses, from Martello Tower No.38, which stood some 800 yards (700 m) distant.

When each of the fuses in turn had been fired, and no effect, save the smoke from the small quantity of 'neat' gunpowder which had been left piled at the end of each of the fuses was seen, 'General Lefroy and three other gentlemen entered the tower'. The only change observed was that the heads of the barrels taking the ends of the fuses had been blown off, and 'a small portion of the contents had been scattered over the surrounding barrels'. The Martello tower with its barrels of gunpowder still intact inside was then comprehensively set afire. 'Nothing approaching an explosion occurred.' Confidence among the spectators increased so much

that 'they continually looked into the building, and they actually went into the building to see how it was burning.'

Impressive though the Hastings demonstration may have been, it did not, so far as can be discovered, move the Ordnance Committee to place an order for protected gunpowder. After April of 1866 commercial confidence in the venture had largely evaporated. Had any at all remained, had, say, the Ordnance Committee given some concrete support to the company in the form of an order for powder, it might have been enough to sustain confidence a little longer. As it was, the attacks were to come hard upon one another during the rest of the summer of 1866.

Like many prophets, James Gale was to be accorded scant honour in his own land. The most damaging of all the attacks upon the reputation of the 'protected' gunpowder came from another Plymouth man, Mr. Johnathan Hearder. It may be entirely coincidental that Hearder was also described as 'an electrician', and additionally as a 'consulting chemist'. The cutting edge of Hearder's criticism of Gale's process was that Hearder's findings were soundly based upon systematic experiment.

The War Office may by this time have turned its face away from the Protected Gunpowder Company's activities. At the least it looks to have been impartial. Hearder acknowledges with thanks the assistance of the 'Captain Superintendent' of the Royal Laboratory at Bullpoint, Devonport, for the loan of a proof-mortar and the services of the 'proofing-sergeant'.

Hearder's findings were published first of all in The Mining Journal. (It has not been possible to get access to the volume of this work for the year 1866; the material which follows is taken instead from The Engineer for 13th July 1866, which reported Hearder's work in some detail).

After dealing at some length with the by then known tendency for the glass powder particles to attract and condense moisture, Hearder lays

out nine points of disadvantage or deleterious effect which he attributes to Gale's process. These points tend to be more than a little laboured and some can without loss be grouped together.

Point '1' stands fairly made on its own. Header asserts, and offers to demonstrate by blowing up a Martello tower with 'protected gunpowder', that Gale's gunpowder was as explosive as any other, when confined. It is assumed that under confinement the hot gases generated by the burning of individual powder grains would force their way through the interstices between powder and glass to ignite others.

Point '2' also stands on its own. The vibration which usually attended the transport of gunpowder by road was shown to shake the gunpowder and the glass into separation. This can be readily appreciated. One of the great disadvantages of the simple gunpowder mixture which the introduction of press-caked gunpowder in the early 1700's had obviated was the tendency for the ingredients to be shaken out into separate layers if the powder was transported for any distance by cart.

Points '3', '4', '5' and '6' are inter-related in that they deal with the additional fouling to both small arms and ordnance barrels which came of the use of powder which had previously been mixed with glass flour, with the abrasive effects of the powder on the bores of the guns, and the abrasive effects of the glass on the gunpowder grains themselves, particularly with the loss of polish and the generation of gunpowder dust.

Points '7', '8' and '9' refer to the difficulties experienced in separating powder from glass quickly enough, and completely enough, for service conditions.

Header's paper was read at the meeting of the shareholders which was called on Wednesday 11th July 1866 at the Guildhall Tavern in London. Mr. Rendle took the leading part in addressing the now

disaffected shareholders. The main part of his speech is embodied in what has already been given of the history of the enterprise. Beyond this the recriminations and accusations lie at the personal level. A little of this can be given for the sake of the atmosphere of the setting it affords. These are nineteenth century scientists and men of business away from their laboratories and offices.

Some attempt was made by Mr. Rendle to make capital out of the information that at least one reputable scientist, Mr. Etheridge of The Museum, Jermyn Street, had declined the offer of £1,000 down and £250 to £500 per year to become the manager of the new company. Rendle suggested that Mr. Etheridge had been deterred from taking the appointment by the advice of his superior at the museum, Professor Hunt, who had said, it was reported, that the company might go on for a few months, but it must collapse. This suggestion was contradicted from the floor by a Mr. Randall who said that what had made Mr. Etheridge decline Mr. Sanders' offer was not any uncertainty about the future of the company, but rather his maturing seniority at the museum, and most particularly his pension.

The Guildhall Tavern meeting revealed that the Gunpowder Trade had been sceptical about the potential of the invention from the very outset. Mr. Sharp of the Ewell Powder Works, Surrey, said that he believed, as a gunpowder manufacturer, that there had been 'nothing in the matter'; he would call it 'simple bosh'. He believed that was the opinion of the trade.

Professor Hunt (Etheridge's superior at The Museum) said that all the gunpowder manufacturers had laughed at the idea from the first, and said that it was of no practical value, and that the experiment took place merely because it happened to be brought before the notice of the Duke of Cambridge, and since the experiment was tried there was nothing to it... he had that from 'one of the largest manufacturers of gunpowder in the country...'

The promoters, Gale and Sanders are the only two named, were absent from the meeting. But they seem to have had some of their partisans in the hall. From the floor a Mr. Hawkins said that he 'had not the slightest doubt that Mr. Sanders would have attended the meeting if he had received a proper circular'. He had known that such a meeting was to be held, but received no proper invitation. Mr. Rendle said that circulars had been sent to Mr. Sanders and to the Directors.

The shareholders' meeting closed when Mr. Rendle proposed that a report of the meeting should be sent to every shareholder, also that a circular asking whether they were in favour of winding the company up be sent. The resolution was adopted and the proceedings were terminated.

If the Protected Gunpowder Company had been wound up amidst a certain bitterness of feeling on the part of the shareholders, Gale himself was not entirely disabused of the notion that he had invented something worthwhile. The principal problem which had dogged the successful promotion of the idea had been the difficulty experienced in separating the gunpowder from the glass flour. But it had been only a mechanical problem. The Mining Journal for 22nd May 1868 carries a short article advertising that Dr. Gale proposed to use a machine recently patented by a Mr. Childs which made it possible for two men to separate one hundred tons of gunpowder per day. From the brief description given the machine would appear to have been a kind of Archimædean screw enclosed within a revolving cylinder of graded wire gauze. There was still a strong element of showmanship in the presentation: 'The quantity of powder stored at Purfleet alone is sufficient to lay all London in ruins'.

It was said at the beginning of this section that there was to be a concern with a few of the personalities associated with the development of explosives. It has been possible to show a little. The men mentioned appear and reappear throughout the rest of the century; sometimes

in material which has to do with explosives, sometimes in material far removed from them. The cautious Sir John Hay's name is often mentioned in material dealing with explosives legislation. The Mr. Siemens who was to design the extensive works at Woolwich was the C.W. Siemens of later electrical fame. From the writer's personal experience it can be said that the Siemens firm had a factory immediately adjacent to the old Woolwich Arsenal at least as late as the mid-fifties of this century. It may be that the young electrician acquired the site of the proposed 'protected' gunpowder factory. The Mr. Bidder who was challenged over his ability to separate gunpowder from glass flour with any speed was proposed for membership of the Institute of Civil Engineers in 1869.

A last reference to Gale's gunpowder was found in the Journal of the Royal United Services, Vol X, p.123: A paper entitled "Gunpowder - Gale's Plan for Rendering it Non-Explosive and Re-Explosive at Pleasure." The author was an M.W. Sanders, and the date was 1883.

CHAPTER 11

DYNAMITE

(1866 - 1878)

The Invention of Dynamite

Nobel's discovery, late in 1866, of the explosive which he was to name 'Dynamite' came at a time when nitroglycerine, the basis of his enterprise, was being banned in many countries because of the serious explosions which had occurred.

The discovery itself could be said to have come about as a fortuitous accident within what had been a long - though entirely systematic - search. As early as 1862, Alfred Nobel's father, Immanuel Nobel, had instituted a series of experiments aimed at discovering a medium for the stabilisation of nitroglycerine.* Notably, he had tried to absorb nitroglycerine into fine grained black gunpowder. This was not satisfactory because only a small proportion of the liquid explosive could be taken up by the gunpowder. Also the grains tended soon to dissolve into the nitroglycerine, whereupon the power of the mixture was found to be much reduced and it became very difficult to explode.

The problem was to find a substance which would take up a large proportion of nitroglycerine without this leading to any substantial loss of the great concentration of energy within small bulk which was the great advantage offered by nitroglycerine.

The accident which led to the finding of an extremely efficient medium for the absorption of nitroglycerine came about because Nobel had found the financial backing to open a factory at Krümmel (Dynamit Aktien-Gesellschaft) a few miles down the Elbe from Hamburg. (This factory had been largely destroyed by an accidental explosion of nitroglycerine during

* A History of Research in the Nobel Division of I.C.I. by F.D. Miles, Pub. I.C.I. 1955.

1866, while Nobel was visiting America). At Krümmel the practice of using a diatomaceous earth, which was locally in plentiful supply, to pack round the tinplate canisters in which the nitroglycerine left the factory, had been adopted.* Of all the materials which might have been used - sawdust, peat, chaff, flock - the diatomaceous earth had the most singular property of being many times more absorbent than anything else tried. It would absorb about three times its own weight of nitroglycerine.

From the point of view of what might be called the mechanics of discovery, there was a very great element of luck in the affair. It was because the factory was in North Germany where deposits of diatomite, kieselguhr, 'white peat' had been in use for some time as an additive to potters' clays and as a fine abrasive that it was chosen as a convenient packing medium. Credit for this must surely go to some un-named foreman or to some enterprising carter.

A Note on Kieselguhr

The result of having a defective canister spill its nitroglycerine into its kieselguhr packing is unlikely to have much resembled dynamite. As it was dug from the silted-up beds of former lakes in and around the Luneburg Heath, the crude kieselguhr was not of uniform constitution: it was mixed with greater or lesser proportions of iron salts, lime, clay and organic material. In order to procure a uniform kieselguhr, two methods of preparation were adopted. Where the deposits of 'guhr' were relatively uniform, the material was refined simply by being 'slimed', a process similar to that employed in the preparation of potters' clay, a simple flotation separation. Less uniform kieselguhr was calcined in furnaces in order to drive off impurities. Calcining caused the kieselguhr to turn the pink colour which was so long associated with dynamite that when it became necessary to turn to other varieties of diatomite as the absorbent medium an addition of ochre was made to retain the accustomed pink colouring.

* The Life-Work of Alfred Nobel by Henry De Mosenthal F.I.C. (p.444), The Journal of the Society of Chemical Industry, 31st May 1899.

It was also necessary to grind down the calcined kieselguhr in a way which reduced the hollow spicules of silica to an approximately uniform size so that the proportions of nitroglycerine absorbed should not vary throughout or between batches.

When the Ardeer factory of the British Dynamite Co. was opened it was necessary at first to import the kieselguhr from Germany; shortly afterwards, however, suitable deposits were found in Stirlingshire.

The distinctive properties of kieselguhr were to serve Nobel extremely well later. The term kieselguhr was held to apply to all absorbent diatomaceous earths. It proved almost impossible to discover any medium which could offer the same qualities. Few explosives - which were not actual infringements of Nobel's patent - could offer the same concentration of nitroglycerine. The point was well made in 1876 when in the case of Krebs v British Dynamite Co. which was taken before the House of Lords. The judgement is said to have turned upon the use of kieselguhr by the British Dynamite Co. within the specification of the patent granted to Alfred Nobel. With the Prussian company of Messrs. Krebs and Co., the importers of 'Lithofracteur', cut off from their British markets the field was then almost entirely clear for Nobel and the British Dynamite Co.

However fortunate Alfred Nobel might have been in the general fall of events, his biographers assert strongly that the discovery was not accidental.

"The invention of dynamite has been ascribed to accident, but this is not the case. Nobel was not empirical in his methods, but always impressed upon those working with him that the days of accidental discovery had gone by and that it is only by systematically pursuing a sound idea that any progress can be made. His choice of materials may frequently have fallen on those nearest at hand, but the fundamental idea of his invention was always the result of experiments conducted on strictly logical and scientific lines."

The Life-Work of Alfred Nobel by
Henry de Mosenthal F.I.C.
The Journal of the Society of the
Chemical Industry, (p.444), 31st May 1899.

(Little may be said here of De Mosenthal's assertions - other than to remark that he was an employee of the Nobel Company. Any general reading of the biographies of the patriarchal founders of large concerns will yield similar interpretations of the events. Biographers sometimes display a distaste for allowing for the workings of Chance - coincidence in biography can carry no greater burden of credence than it does in fiction.

The Founding of the British Dynamite Company

An introductory note is necessary here to make clear a necessary distinction between two sources of material. Almost all of the sources consulted for the rest of this study have been contemporary sources: books, journals, and magazines which were printed and in circulation at the time. Only occasionally has it been found necessary to resort to more secondary sources. And where this has been done it has usually been the case that the particular writer concerned - Cundill, Abel, Guttman, Marshall - was able to record personal experience of much earlier events.

In treating the topic 'Dynamite' a difficulty arises. Dynamite cannot easily be discussed apart from some consideration of its inventor. And Alfred Nobel has been the subject of a number of exhaustive biographies. Some of these works have been little better than Company sponsored eulogies; some have been more critical. But without exception, and for very good reason, they have all been well researched. The material, in the form of sound primary sources, exists. Alfred Nobel kept excellent records. He also wrote up his work in clear idiomatic English.

This presents a problem. Nothing useful would be accomplished by taking material directly from modern works. But because the contemporary material which it has been possible to locate is sparse, it has been

necessary to supplement it, to shore it up, with other quotations taken from biographies written during this century. If this were not done the new material would have had to have been presented in a disjointed fashion which could not have helped understanding.

Knowledge of Nobel's Invention slowly disseminated

As has already been said, Nobel invented his dynamite towards the end of 1866. It is remarkable that the earliest information about the new explosive which can be found in the English popular journals appears in a letter printed in Engineering on 13th March 1868, some fifteen to eighteen months after the discovery. Nobel had secured legal protection for his invention in the United Kingdom from the 7th May 1867 when he had been granted British patent No.1345. And yet there was apparently no great advertisement of the invention. The correspondent to Engineering clearly thought he was reporting something new; the magazine's editor may be supposed to have thought the information novel enough to print.

"Dynamite

To the Editor of Engineering

Sir - Thinking you might like to see a report of some experiments made with the new blasting powder, I take this from a Norwegian paper:

'Alfred Nobel, the introducer of nitroglycerine as a blasting powder (which came into universal use in the last few years, on account of its superior strength ...) has invented a combination which is called dynamite or Nobel's powder, which has all nitroglycerine's good points ... and but few of its bad ones, as it will not explode by percussion or heat of a flame, but is only explosible by a peculiar method.' (which is not named further in the article, so suppose it as yet a secret).'

(The letter goes on to describe a set of four experiments which involved the blasting of granite and thick ice).

Several reasons could have inclined Nobel to wish for a localisation of information about his invention. The most important reason for discretion was likely to have been that he needed time to establish his patent rights in all countries where this was possible. In some countries on the Continent - notably Austria - patents were 'sealed', that is to say secret, so that once secured the information was not available to anyone without special leave from the patentee. But in the case of the United Kingdom, at least, patents were open to inspection, and thus to attempts at circumvention and infringement.

With his Krümmel factory destroyed Nobel was unlikely to have been able to supply any great demand for dynamite, no matter how great. During 1867 only eleven tons of the new explosive were produced.* It is also important to remember that Nobel's other factories, those in Finland, Norway, Sweden, and Bohemia, were in operation before 1867 and would have had to operate within their own market conditions. Existing stocks would have had to have been disposed of first: it would have been unprofitable to have held on to nitroglycerine already produced until kieselguhr could be imported to convert it into dynamite.

Scottish Finance: The British Dynamite Company

The following is a short synopsis of the main events surrounding the formation and the first years of the British Dynamite Company. This is given as a necessary string of general business history upon which to thread the various topics in the history of technology which will afterwards be treated in more detail. The sources for the synopsis are essentially modern and will be cited below.

Nobel was negotiating with the Glasgow merchants through J. Downie as early as before 15th June 1868. At this time, however, he still had hopes of raising capital in England. Though he had not approached the major banking houses for support.

* Imperial Chemical Industries Ltd., and its Founding Companies, I: The History of Nobel's Explosive Company and Nobel Industries Ltd., 1871-1926, Pub. I.C.I. London 1938, Ch.10, p.47.

The passing of the Nitroglycerine Act precluded the setting up of a site in England or Wales. But, under certain conditions, a factory in Scotland could be licensed.

John Downie applied for a licence. There was a very long delay, during which Downie was occupied simply in finding out the conditions under which a licence might be granted. Licences were to be granted only for the production of nitroglycerine in-situ - this made factory production impossible. The regulation was the work of Abel.

A licence for the Ardeer factory was at last granted in 1871.

John Downie was to form a public company with a capital of £24,000. The company was to buy and work the rights in Nobel's British patent. Nobel was to be technical advisor and he was to allow the firm access to any improvements he might make to his existing patent. The final outcome of the negotiations was that Nobel was to hold half of the capital investment - he was the largest shareholder but had not legal control over the enterprise.

The Glasgow investors were slow to pay the capital they had subscribed. Nobel threatened to withdraw.

The Ardeer factory was built in some fashion during 1872; production of nitroglycerine and hence of dynamite began in 1873.

The story of the Nobel Explosives Company as an example of the growth of a Trust is commonplace of Economic History.

The Ladywell Quarry Trials

The edition of The Practical Mechanic's Journal for 1st July 1868 (p.106) holds an account of a series of experimental blasts which were carried out at 'Faill's Ladywell Quarry, Duke Street, Glasgow, on Monday 15th June of that year. These experimental explosions were the usual way of promoting any new explosive product. In the case of the Ladywell

Quarry demonstration, Nobel himself was present. The purpose of the experiments was to show potential Scottish investors that dynamite was not only safe but also that it was extremely powerful. Nobel was to hold similar trials in England, at the Greystone Lime Works, Merstham, near Redhill in Surrey, during July of 1868.*

Within the account of the Ladywell Quarry blasts, however, there are a few striking indications that there was already an appreciation of the range of performance that had become possible with the introduction of dynamite.

The account is long so only those three of the experiments which best illustrate high explosive phenomena will be quoted:

"Experiment No. 8 - A bar of malleable iron six inches (15.24 cms) in length and $1\frac{1}{2}$ inches (3.8 cm) in diameter, accurately turned, was placed in a wooden cylinder, with one half projecting outside, while the space between the inner and the outer half of the bar and the walls of the wooden cylinder was filled with about $\frac{1}{2}$ lb. (267 gram) of dynamite, which was then fired, when that half of the iron which was enclosed in the cylinder was found to be $\frac{1}{32}$ of an inch (0.08 cm) less in diameter than the half which projected beyond it ... it pointed out also the peculiar local effect it possesses; for whilst the explosive effects of the other agents usually spend themselves in the direction of least resistance, this, most singularly, acts in a more decided way upon objects nearest to it, whether situated in the direction of least resistance or not..."

And later:

"Experiment No.11 - A wooden cylinder of the same kind used in Experiment No.8 was charged with $\frac{1}{2}$ lb. (267 gram) of dynamite, and a tinplate placed before the mouth; this was placed about twenty inches (51 cm) from two boiler plates, each $\frac{3}{8}$ ths of an inch (1 cm) thick, and touching each other; the fuse was then lighted, and the effect of the explosion was to

* A concise account of the Merstham experiments is given in The Practical Mechanic's Journal for 1st August 1868. These trials were more widely reported than those at Glasgow.

drive that portion of the tinplate which was opposite the centre of the cylinder through both of the plates, making a hole in each sufficiently large to admit one's finger. The thickness of the tinplate was about $1/64$ of an inch (0.04 cm)..."

Here is an account of what is almost an example of the 'shaped-charge' phenomenon (The Munro Effect): a slug of metal is placed at the bottom of a cone-shaped cavity made in a charge of high explosive; when the charge is detonated, the metal is vapourised and is able to punch a hole through resistant material within the line of explosive force.

"Experiment No.12 = About $\frac{1}{4}$ lb (.113 kg) of dynamite was placed on a block of stone weighing from 3 to 4 tons (2.95 tonnes - 3.94 tonnes); a fuse fitted with a cap was then placed in it, and the whole covered up with clay, and the effect of the explosion was to crack the stone in such a manner that a few blows with a dressing hammer and chisel were only necessary to make it ready for the builder's hand."

The above described experiment is an example of the practice which has come to be called 'mudcapping' and is still in common use for precisely the same purpose today.

It can thus be said that within a little more than a year of its invention three at least of the most useful techniques for the practical use of dynamite as a high explosive had been worked out.

The Nitroglycerine Bill and the Nitroglycerine Act

The Nitroglycerine Bill and the subsequent Nitroglycerine Act (32 and 33 Victoria, cap.113) of 1869 have already been alluded to in a foregoing section of the work, in connection with the doubtful testimony given by Professor Abel to Sir John Hay M.P. about the dangers associated with the handling of frozen nitroglycerine. Some further discussion of the topic is warranted here because the passing of the Nitroglycerine Act was to have far-reaching effects upon the way in which the nitroglycerine explosives were developed in the United Kingdom. The discussion has been reserved until now because it is felt that, while the legislation was put in hand to restrain the use of nitroglycerine, its effects were to fall more directly upon the newly discovered dynamite. Indeed by the time the Act was passed, very little nitroglycerine - used alone - was being employed in blasting at all.

If nitroglycerine, with all its dangers and defects, had been seen as a threat to the demand for gun-cotton, dynamite, which was as safe as gun-cotton, more convenient to use, more powerful, must have offered to drive gun-cotton entirely from its markets.

A major threat required a major response. To have fostered the rumour that nitroglycerine was unstable when frozen had clearly not been sufficient. Stronger action was needed. The gun-cotton interest (Messrs. Hall & Sons et al, and their principal agent, A.F. Abel) was also the British interest. Gun-cotton was already in use, it used a raw material imported from British colonies; there was, perhaps above all, already a considerable capital investment in the means of making the explosive. Nobel, on the other hand, was a foreign interloper, in the older sense of that word. The gun-cotton interest probably felt

fully justified in using their country's legal and parliamentary system in the way they did.

Material only sufficient to treat the main articulations of the episode can be offered here. But, as was the case with Gale's Gunpowder, it is hoped to show that the Explosives Industry had much the same background as any other during the nineteenth century.

The Bill was introduced into the House by a Mr. Alderman Lawence, M.P. and a Mr. Graves, M.P. The ostensive reason for the introduction of the Bill was that there was good evidence to show that quantities of nitroglycerine liquid had been carried about in and stored in both London and Liverpool.

In the case of Liverpool there were proper grounds for complaint. Under the terms of The Liverpool Gunpowder Regulation etc. Act of 1865 (28 and 29 Victoria, cap.278), the Corporation of Liverpool was empowered to regulate the passing of explosives from shipping in the Mersey. There were large powder magazines at Wallasey.* Under the terms of The Carriage and Deposit of Dangerous Goods Act, 1866 (29 and 30 Victoria, cap.69), nitroglycerine was specifically named as being 'specially dangerous', and it was ordered that any package of nitroglycerine was to be clearly so marked.

Yet, in the face of both of these pieces of legislation, it was discovered that the nitroglycerine which had exploded at Cwm-y-Glo (The Caernarvon Explosion) had passed unmarked as such through the jurisdiction of the Mersey Docks and Harbour Board. The consignment was ordered by Orlando Webb, in his capacity as Director of the Glyn Rhonwy Slate Company. The gun-cotton interest could hardly have wished for a better opportunity.

The Nitroglycerine Act was passed. The dubious conditions under which it was passed and its defects as a piece of legislation were fully advertised by the supporters of Nobel. The following represent a good

*The Times, 30th June 1851, 2a.5e.

sample of the cry of foul play which afterwards arose in the journals:

"The dissatisfaction which at present exists with reference to the laws on explosives, has reference largely if not mainly to the Nitro-glycerine Act ... which was hastily passed through Parliament on the 11th August 1869 ... and so hastily was the Act passed through the House, that in the title it is stated to be an Act 'for a limited Period' although no period is named in any of the clauses. The fact is that the Bill limited the Act to one year, but this limitation was struck out by Mr. Bruce in committee, and the amendment to the title was omitted to be made..."

Engineering, 1st May 1874 (p.319)

And again:

"It would doubtless appear strange that dynamite - possessing as it does so many great advantages - should be so little known and so very much less used in England. The truth is that dynamite would undoubtedly have had as great a run in England as on the Continent, and had it not been that a short Act was quietly smuggled through Parliament during the Session of 1869. It is known as the 'Nitroglycerine Act' and it virtually prohibits the importation, exportation, manufacture, sale, or even the possession of 'every substance having nitroglycerine in any form as one of its component parts or ingredients.' The Act is a very snug little affair, and if not promoted by the gun-cotton party, why then it ought to have been; it cannot fail, however, to afford them much satisfaction."

(The writer goes on to describe the effectiveness of the Act's provisions in virtually suppressing dynamite in the United Kingdom).

"It will thus be seen that extraordinary impediments have been thrown in the way of the use of dynamite in this country, and the consequence is that no more than 20 tons (19.7 tonnes) have been sold in Great Britain since the Act was passed. Messrs. Webb and Co. of Bangor are the agents for Mr. Nobel - whose factory is at Lauenburg (Krummel) - but they inform us that they are literally doing nothing, although they have constant applications for the material ... managers are constantly pressing for further supplies, but of course to no purpose."

Engineering, 22nd September 1871 (p.183)

It will be noted that licence for the importation of at least some dynamite had been granted during the two years which had gone by since the passing of the Act. Exceptions were allowed.

"But the Act also provides that licences shall be granted for the manufacture etc. of nitroglycerine compounds, if it can be shown that these substances can be safely made and used. And as a matter of fact several nitroglycerine compounds have been licensed by the Home Office, and are being made and used. But the conditions imposed under the nitroglycerine Act are hampering and restrictive, especially as regards transport and storage, only very small quantities - 5 cwt. (.246 tonnes) - of any compound being allowed to be conveyed from place to place at one time.

Engineering, 1st May 1874 (p.119)

Here it should be remarked that Professor Abel had himself taken out a patent, British patent No.3,652, as long before the passing of the Act as the 24th December 1867, for an explosive which he had named 'Glyoxiline'. This was a mixture of gun-cotton and nitroglycerine. It may be that Abel was able to get a licence for his later work with 'Glyoxiline'. If he was not, the personal sacrifice ~~was~~ not great. 'Glyoxiline' was not a success.

The opponents of dynamite had at least equal access to the journals, and made use of the right to propound their views. The following is a short sample of the heavy-handed way in which the semantics were manipulated in the argument:

"The serious objections to the use of nitroglycerine appears at last to have been recognised by its chief supporter, Mr. Nobel, who was induced to contrive a mode of applying the substance which, by disguising the liquid, might rob it of some of its terrors, and render it ... The result of his labours has been the production of a buff coloured powder, somewhat oily to the touch, which, under the name of 'dynamite' has recently been brought under the notice ... is in reality a somewhat crude

nitroglycerine preparation, and consists simply of a siliceous earth (or any other inert powder) impregnated with a considerable quantity of nitroglycerine."

Engineering, 27th November 1868, p.138

Both sides were able to insert their comments into articles which were otherwise straight technical narratives.

After the 11th August 1869 the Nobel Company was effectively excluded from selling either nitroglycerine or dynamite in England. It was a serious reverse.

"Great Britain is in my opinion by far the most important of all this branch of business, not only on account of the vast international trade but also the great facility for export to the colonies ... think of all the Indian railways, Australian mining and so forth.

Alfred Nobel to John Downie
April 1869 NC XII(3)

Cited in:

'IMPERIAL CHEMICAL INDUSTRIES AND ITS
FOUNDING COMPANIES' VOL.I: 1871-1926,
I.C.I., London 1938.

(The above will also serve to show that Nobel was in contact with the Scot, John Downie, before the passing of Nitroglycerine Act).

But for certain purposes Scotland has a degree of autonomy. The writ of the English Home Office applied then, as now, only to England and Wales. Scotland came under the Scottish Office - at least so far as the issue of licences for the erection of explosives factories was concerned. And it may have dismayed Abel and his associates to learn that not only was Nobel able to circumvent the new legislation, but also that there was sufficient capital at large in Scotland to raise the investment necessary to build a United Kingdom factory. Doubtless the Glasgow merchants had every bit as much influence at the Edinburgh Scottish Office as Abel had had at the London Home Office.

It may also be that the losses incurred by the largest manufacturer of gun-cotton, Prentice, as a result of the Stowmarket Explosion of 1870, made for a diminution in the trade's capacity to fight incursions.

If the Nitroglycerine Act can be said to have accomplished anything, it is that it must have at least averted many accidental explosions in small manufactories. Nitroglycerine was easy to make and required little in the way of plant. The making of fanciful 'patent' dynamite-type explosives by inventor=proprietors of the same sort who dabbled in chlorate compositions was made unattractive by the legal penalties provided for in the Act: imprisonment for one year, with hard labour, or a fine of £500.

In turning to the use of legislation as a weapon in what was essentially commercial competition the home explosives industry may well have hastened the institution of the more stringent controls which were to come with the Explosives Act of 1875.

The Site of the Ardeer Factory

Nobel himself is said to have chosen the Site of the Ardeer Factory of the British Dynamite Company from among several picked out by John Downie beforehand.* He recorded his own impressions:

"Picture to yourself everlasting bleak dunes with no buildings. Only the rabbits find a little nourishment here; they eat a substance which quite unjustifiably goes by the name of grass and of which some few traces are to be found here and there. This is a wonderful sand desert, where the wind always blows, and often howls, filling ears with sand which also drifts about the room like fine drizzle. There, like a huge village, lies the factory, and most of the buildings have hidden themselves behind sandhills. A few yards away the ocean begins ... without work it would be intolerable.

Imperial Chemical Industries Ltd. and its
Founding Companies, I: The History of
Nobel's Explosive Company and Nobel Industries
Ltd. 1871-1926, Pub.I.C.I. London, 1938 (p.22).

As a site for an explosive factory Ardeer offered many advantages. As a location it was remote and, as events were to show, it was vulnerable. There were very many other sites within the United Kingdom which would have offered more general advantages. The main influence which determined the choice of Ardeer was that the Glasgow shareholders wanted an oversight of their investment and no doubt a chance to share in any incidental business.

The actual site was 'a stretch of sandhills, 1,000 yards (914 m) long by 600 yards (549 m) deep ... on the shore of the Firth of Clyde, about a mile from Stevenston and a mile from Irvine'.

Access to the sea, either directly from the open roadstead:

"a few cases at a time were manufactured and carried by men and women to the beach, and then taken through the surf to be loaded into boats in the most primitive manner."

RISE AND PROGRESS OF BRITISH EXPLOSIVES
INDUSTRY, London, 1912 (p.112)

or from the little port of Irvine. The option of loading dynamite into coasters directly was important; but a far greater advantage came of being able to make up a large cargo of explosive for transhipment directly into the holds of ocean-going vessels anchored in the Firth of Clyde. In this way the port of Glasgow would be spared the hazard of having the dynamite pass through it; and incidentally the owners of vessels loading dynamite in this way would be spared certain port dues. The subject of the sea transport of dynamite will be treated as a separate topic presently.

The Glasgow and South Western Railway line ran close to the Ardeer site. At some time in the firm's history a special branch line to the factory was built, but exactly how long after the setting up of the firm this was is unclear. The railway transport of dynamite will also be treated under a separate heading later in this section of the work.

The sand dunes of the Ardeer shore were seen as ready-made blast-walls for the protection of the factory buildings in the event of accidental explosion. They also had a secondary function which is little mentioned in the literature; the slope of at least one of the dunes allowed the 'one in sixty five'* fall which permitted the nitroglycerine and the waste acids to flow by gravity down to the next stage of the process. The term 'Nitroglycerine Hill' which referred to such a dune at Ardeer was elsewhere attached to something quite different. At factories other than the one at Ardeer, the term was a common rather than a proper noun in that it indicated a magazine which was protected by being buried under a flat-topped pile of earth or sand.

Over all, the Ardeer must have proved to have been a satisfactory site - it is still being used for the large-scale production of nitroglycerine explosives.

Industrial Plant at Ardeer

The Ardeer factory of the British Dynamite Company went into production on the 13th January 1873 when a charge of 1500 lb. (680 kg) of nitroglycerine was made. Nobel's lifelong friend and fellow countryman, Alarick Liedbeck designed and supervised the construction of all the plant at Nobel's factories. The nitration apparatus at Ardeer was designed to handle ten charges of nitroglycerine a week.**

Ardeer, for whatever reason, looks to have been working at less than the capacity Liedbeck had provided for. At the stated capacity the annual output of nitroglycerine should have been of the order of 335 tons (330 tonnes); it was 170.25 tons (165 tonnes), 227 tons (223 tonnes) of 'No.1' dynamite (1,500 lbs. x 10 = 15,000 lb. = Output for notional 6-day week; $\frac{15,000}{6} = 2,500$ lb.per day. Allow a working year

* Explosives, A.Marshall, Pub.J.A. Churchill, London 1917, Vol.I (p.227).

** Imperial Chemical Industries Ltd. and its Founding Companies, I. The History of Nobel's Explosive Company and Nobel Industries Ltd. 1871-1926, Pub.I.C.I. London, 1938, p.152.

of 300 days : 365 days - 52 Sabbaths and a notional thirteen days for other losses of production and holidays. The annual output might thus be expected to have been 750,000 lbs or 334.8 Imperial tons (330 tonnes) approximately.

The information that the nitration apparatus designed by Liedbeck made a batch of 1,500 lbs. of nitroglycerine allows us to make some estimate of the capacity of that apparatus:

1. 1500 lbs. = one load of nitroglycerine.
2. One cubic foot of water = 62.5 lbs.
3. One cubic foot of glycerine = 62.5×1.265 (s.g. glycerine) = 79 lbs. per cubic foot.
4. One cubic foot of nitroglycerine (allowing for an increase of approximately 20 per cent during the nitration process) = 95 lbs. per cubic foot.
5. $\frac{1500 \text{ lbs.}}{95 \text{ lbs}} = \underline{15.8 \text{ cubic feet per load}}$
6. Allow a layer of nitroglycerine at the bottom of the vat of one foot thickness, then
- 7(a) the vat could have been only 15.8 = , approximately
4. 4 ft. x 4 ft., or
- (b) $\frac{15.8}{3.14159} = 5 = r^2$ and 5 = 2.2 radius, 4.4 ft. dia.

The vat or container could have been quite small in its dimensions

Metric equivalents:

1500 lbs. = 680.29 kg.; 62.5 lbs. = 28.35 kg., 35.8 kg.

15.8 sq.ft. = (approx) 1.48 sq.metres.

Since the reaction time for the making of nitroglycerine was not long, it can be supposed that the nitration of the glycerine was not a continuous process during the early days. Two charges a day for five days each week would produce the quantity which Liedbeck had had designed the plant to produce.

It can be said that the small scale of production operating between 1873 and 1876* did not go on. Certainly, by 1883 George M'Roberts who became Chief Chemist to the Company at the beginning of February 1873, following Alarik Liedbeck's return to Sweden, was to speak in a public lecture of batches of 7.5 tons (7.4 tonnes) of nitro-glycerine being run at one time. The plant to handle this scale of production must have been very much larger and would have needed appropriate housing.

The nitric acid for the process was made by the 'pot process': sulphuric acid was distilled with Chile saltpetre in batteries of cast iron containers. This process is described and illustrated in detail in the 1872 edition of Wagner's A Handbook of Chemical Technology (Trans. W. Crookes F.R.S.). The Company drew its sulphuric acid from a factory at nearby Westquarter which it had bought from George M'Roberts.

The Mixing of Dynamite

Kieselguhr dynamite, 'Dynamite No.1', which was the only dynamite permitted to be manufactured in the United Kingdom, was mixed by hand. Oscar Guttman** gives a close description of the process. However, from the phrasing of his description, Guttman was drawing on his experience of more than one factory, and this across a considerable period of time, after 1875. The specific procedures followed at the Ardeer factory are not mentioned by Guttman.

Nitroglycerine liquid was taken directly from the nitration and washing stages of the manufacture and run at once into zinc-lined 'trolleys' containing a quantity of calcined and lightly ground kieselguhr sufficient to form a 'paste' when mixed with the explosive. This allowed

* Lecture delivered by Mr. G. McRoberts, 25th April 1883 before the Glasgow Philosophical Society. Quoted in Thorpe's A Dictionary of Applied Chemistry (p.72), Pub. Longman Green, London 1891.

** The Manufacture of Explosives, Oscar Guttman, Whittaker, London, 1895, Vol.II (p.192).

the nitroglycerine to be moved about the factory with much greater safety.

The second mixing was done with the operatives' bare hands, on tables covered with sheet lead. Additional kieselguhr was added until the paste became a stiffish putty. Only by working with their bare hands could the workmen ensure that precise fineness of touch which allowed them to know when the mixture was so proportioned that there was no free nitroglycerine present, nor any un-used absorbent capacity. It can be supposed that the kieselguhr was not of a uniform nature.

The workmen were said quickly to have acquired an immunity to the well known physiological ill-effects associated with contact with nitroglycerine; though it was also known that the immunity was soon lost and the discomforts, the headaches and the nausea, had to be endured afresh if there was a very long absence from the work.

The stiff mixture resulting from the second processing was in the form of well-kneaded lumps. In order to ensure that the kieselguhr and the nitroglycerine were thoroughly well incorporated the mixture was forced through a mesh of brass wires held in a wooden frame. Guttman gives the meshes as being of seven to the Imperial inch (2.540 cm.) Again this operation was carried with the bare hands and a wooden spatula. It is reasonable to visualise the outcome of this part of the manufacture as small pellets of dynamite. The most likely reason for this extra operation would seem to be elimination of any remaining cavities or bubbles which might hold unmixed nitroglycerine.

The final stage of manufacture came when the dynamite, in the form of pellets or crumbs, was pressed into cartridges and wrapped in waxed or 'parchmentised' paper.

All of the machines shown in the literature of the seventies are hand-operated. The most common types are shown as either upright,

post, piston and lever presses, or as screw extruders of the type still to be found in use as kitchen mincers.

Later machinery was introduced for all of the operations described above. When this was done cannot be said with any confidence. Machine processing had been introduced at Ardeer by April of 1883 when G. McRoberts, F.C.S. read his paper on the workings of the Ardeer Factory.* A best guess for the date of the introduction of machinery would be 1877 when the firm was reconstituted as Nobel's Explosives Company after having been the British Dynamite Company since its formation.

The Properties of Dynamite

The principal advantage offered by the new explosive was that it was stable.

"The stability of dynamite has been practically confirmed by extensive and daily use in mines on the Continent, and by a limited use in England, as well as by the large quantities which are stored at the factories. Beyond this, the most careful investigations have shown that there is not the slightest ground for apprehension on that score. Under continued exposure to the direct rays of the sun during the whole of the summer of 1868 - an exceptionally hot one - not the slightest chemical change could be detected..."

Engineering, 22nd September 1871 (p.183)

Dynamite could not be fired by the spurt of flame from a fuse. It required the use of a blasting cap to initiate the explosion.**

Confidence, beyond certain bounds of prudence, in the stability of dynamite could be fatal. In giving his testimony to the Parliamentary Select Committee on Explosive Substances, in 1874,*** John Downie, the first manager of the British Dynamite Co., had answered the question

* See McRoberts' Lecture cited above.

** The Life-Work of Alfred Nobel by Henry De Mosenthal, F.I.C. (p.444), Journal of the Society of Chemical Industry, 31st May 1899.

*** Report of the Select Committee on Explosive Substances, 1874.

"You would have no fear whatever, I suppose, in setting fire yourself to half a dozen 50 lb. (22.6 kg) boxes loose?", with an unequivocal answer of "None whatever". A few months later, in the January of 1875, John Downie went to Cookhaven, in Ireland to dispose of a consignment of dynamite which had deteriorated in a ship's hold. He lit a fire and fed it with loose cartridges. There was an explosion and Downie died soon afterwards.

It occurred at once to the detractors of dynamite that the combination of nitroglycerine with kieselguhr would result in some loss of explosive power. Abel was quick to point this out.* But there were others who were inclined to set this disadvantage aside. Mr. Perry F. Nursey, in his series of articles, "On Explosive Compounds for Engineering Purposes", which appeared in The Engineer for 12th March 1869 (p.186) wrote:

"It has been urged in some quarters that the addition of silica to nitroglycerine constitutes a dead loss of explosive power. This, however, is a mistake. Practically speaking, there is no loss whatever. The dangerous properties of nitroglycerine, leakage into crevices ... render it absolutely necessary to make use of cartridges which leave a considerable air room in the powder chamber ... dynamite readily fills up the bore hole, and leaves no empty space. Practically, therefore, a bore-hole charged with dynamite will hold fully as much nitroglycerine as when it is charged with the liquid explosive oil, so that the silica is no drawback..."

It can be suggested that where the very hardest rock had to be drilled by hand there would still be a use for the greater power of the pure nitroglycerine. A margin of 25 per cent on the capacity of a bore-hole might not always have been off-set by the extra safety engendered by the use of dynamite.

* Minutes of the Proceedings of the Institute of Civil Engineers, Vol.XLV. No.1342 - "Exp. An. App'd. Ind. Purp." F.E. Abel etc.

Notwithstanding the significant loss of blasting power which the substitution of dynamite for nitroglycerine brought, the plastic explosive was still powerful enough to be very economical in use, and in any event much more so than the available alternatives. The journal Engineering for 22nd September 1871 (p.183), quotes Nobel himself on the relative power of his invention:

"With regard to the power of dynamite we may observe that its destructive power is estimated to be about ten times that of an equal weight of gunpowder. If, therefore, we take the average work done by 1 lb (.45359 kg) of gunpowder at 32,832 lb.* (15 tonnes) - and average obtained from actual practice in six different places and in various kinds of rock - we get 32,320 lbs. (144 tonnes) or about $146\frac{1}{2}$ tons, as the work done by 1 lb. of dynamite. Hence, although its cost is greater ... its use is attended by greater economy ... in one mine in Cornwall as much as 50 per cent John del Rey Mining Company doubled their workings at two thirds the cost of gunpowder ... this same company saves £1,000 per month by the use of dynamite."

The readiness with which nitroglycerine separated out from its stabilising kieselguhr was a defect that was remedied by encasing the dynamite in cartridges made of waterproofed paper. The disadvantage was not a great one. Only where the dynamite was being used for blasting under water, and where there was a strong current, would there have been any need to provide for additional casing. Where it was desired to get hold of some nitroglycerine liquid it would have been simple enough to dissolve dynamite cartridges in water.

Dynamite froze at an even higher temperature than nitroglycerine. The freezing of nitroglycerine has already been discussed in a foregoing section of this work. What was said of nitroglycerine will largely hold for dynamite.

*Probably 'foot/pounds'

Accidents with Dynamite

Although dynamite was very much safer to handle and to store than nitroglycerine it was nevertheless still an explosive - and at the point of use it was as dangerous as any other unless carefully managed. Very many accounts of accidents which occurred during the first years after dynamite came into use in the United Kingdom could be adduced, but such descriptions would nearly duplicate the examples already given in the discussion on the use of nitroglycerine. Here a more general piece of contemporary testimony will be used. The evidence of Dr. C. Le N. Forest (Inspector of the Western District: Somersetshire and Dorset) given before H.M. Commissioners and Inspectors on Mining Accidents and the Employment of Explosives in Mines 1868 - 1881, Mining Accidents 10, 27th May 1879 (p.129).

"4106. You have had, I see, a considerable number of deaths to report from the use, the very extended use, of dynamite; are these now falling off in number as the men are becoming better acquainted with it? - I still have a great many dynamite accidents.

"4107. Perhaps you would state to the Commission what has been the usual or the prevalent cause of accidents with dynamite? -

I have had six fatal accidents and seven deaths from dynamite from 1873 to 1878; four deaths appear to be due to remnants of dynamite left after partial explosion of the charge, which went off when men were working in the same hole or in the bottom of the hole. Two fatal accidents from boring into charges of dynamite that had missed fire ... And then I have one fatal accident from putting a charge of dynamite into a hole that had just been fired with powder, the powder had not done its work, and the dynamite was put in and went off."

There were in addition accidents where no deaths were reported

* Irish University Press Series: 10, Mining Accidents, British Parliamentary Papers, Shannon: Ireland.

but where, nevertheless, workmen were injured.

"4109 ... I have had 25 non-fatal accidents with dynamite, causing injury to thirty six persons, and I have classified them into six classes. Class one, 'boring or working near missed charges or places where charges had missed fire and had been subsequently fired off,' ... Class two, 'cleaning out holes where dynamite remained, eight accidents and eleven persons injured..."

The Commissioners enquired closely and extensively into accidents associated with the use of the new dynamite explosive.

The Transport of Dynamite by Railway

The nearness of the line belonging to the Glasgow and South Western Railway Company was probably one of the factors taken into account when the Ardeer site was chosen. But access to the line of a single company was not, in those days of numerous independent companies, the same thing as access to the railway network of the entire United Kingdom. The history of the relations between the British Dynamite Company (and its successors) and the railways, almost as a whole, was to be one of a hard and uneven struggle on the part of the makers of dynamite, against an attitude, expressed in policy, of, apparently, obstructive over-caution on the part of the railway directors.

The reasons behind the decades of embargo against dynamite can only be guessed at, without deeper research beyond the period under study. Certainly there was more to the business than a concern for the companies' rolling stock and passengers. Other explosives were carried, subject to certain safety requirements, more or less freely.

From the outset, the need to convince the railway companies of the safety of dynamite in transit had been appreciated by the British Dynamite Company. Only a matter of a fortnight after the first dynamite had been made at Ardeer the company had thought it expedient to stage an

extended demonstration. This was not to be, as before, an exhibition of dynamite's power; it was designed to be a dramatic demonstration of the explosive's stability. The journal Engineering reported the experiments at length. Only the first of the nine experiments, which is typical of the rest, will be quoted here:

"First Experiment - This experiment ... performed with the view of demonstrating the safety with which dynamite may be handled, and stored, and carried by railway. The substance was subjected, in Mr. Nobel's hands, to such treatment as rarely happens in connection with ordinary railway traffic; indeed, it was so rigidly severe as to suggest the total impossibility of producing an explosion with dynamite under any condition of things that is within the bounds of probability in the shape of railway collisions, falls from waggons, goods stores, etc.

There had been extemporised a sort of wooden tower of sufficient height to give a vertical fall of 40 ft. (12.2 m). To the top of this so-called tower there was hoisted a deal box containing 50 lb. (22.9 kg) weight of dynamite cartridges; when the signal of 'All clear' was given, it was permitted to drop down upon a very solid mass of woodwork. The box was severely shattered by this concussion, and the cartridges were freely scattered about, but there was no explosion."

Engineering, 14th February 1873

That resistance to the free passage of dynamite on the railways did not come from those best equipped to judge the degree of hazard entailed is also indicated at the beginning of the article cited above.

"The traffic managers of all the Scottish railways have been for many months thoroughly satisfied of the almost total immunity from danger ... under all conditions of carriage, as they personally 'assisted' at numerous experiments performed at the request of the Railway Clearing House Committee by Professor Bischof of the Young Chair of Technical Chemistry, Glasgow..."

(The name of Professor Bischof recurs in connection with the British Dynamite Company).

But the opinions of employees, even of professional employees, in Scotland, was not to weigh at all with the representatives of the English railway companies. In a long article in Engineering for 12th June 1874, The Laws of Explosives, which reported on the progress of the enquiry carried out by a Parliamentary Commission as a preliminary to the passing of the Explosives Act of 1875, this was made clear in the reported testimony of witnesses:

"Mr. Kay, who attended Mr. Cawkwell, on behalf of the London and North Western Railway Company ... his company and most others, had their own opinion upon the subject of nitro-glycerine compounds ... notwithstanding all that had been done to show the safety ... the witness went so far as to say that his directors preferred that other companies should experiment with ... carrying these compounds."

It is not difficult to posit a possible reason for the railway companies' unwillingness even to consider carrying dynamite on their lines. As has already been said, they carried more dangerous loads every day. The thing most likely to have caused the railway companies to maintain their embargo for so long was the fear that by agreeing to carry dynamite they would have angered the manufacturers of other explosives. The embargo was a manifestation of the continuing and fierce competition between the makers of gunpowder and gun-cotton which had first shown itself in the passing of the Nitroglycerine Act. And with the rapid consolidation of the explosives industry under the control of Messrs. Curtis & Harvey, this must have constituted a formidably powerful force.

The power of the explosives industry over the railways lay in the

quantity of freight that the industry employed the railways to carry. The sheer volume of rail freight generated by the makers of black gunpowder alone was very many times that of the British Dynamite Company's output. It has been shown that the tonnage of gunpowder alone from the Port of Glasgow in 1872 was more than 675 tons (686 tonnes). Although the weight of powder made continued to diminish as the century progressed, it was a long time before the railways agreed to carry dynamite - 1893. Dynamite is neither heavy nor very bulky. Gunpowder, especially the larger grained gunpowder, is bulky. And freight is determined by the space taken up on a train. The volume of gunpowder produced in the United Kingdom, even after 1875, was still enormous when it is considered just how many uses there were in which gunpowder was unchallenged: all naval and military ordnance at home and abroad, all military small arms ammunition, much blasting powder, especially that sent for export, and all 'trade' gunpowder. And the freight would have been paid on the raw materials in as well as upon the finished powders out.

Some lines would carry dynamite - at a price. The following testimony was given at the same enquiry as that cited above, and it was reported in the same journal.

"Mr. Downie, Manager of the British Dynamite Works ... and the difficulties of transport. These difficulties were referable to the objections of the railway companies to carry nitroglycerine compounds, although their safety had been amply proved. There were two exceptions, and those were two railways in the North, but they charged enormously high rates for carrying it. The most they would carry, said this witness, was two tons (2.064 tonnes) in any one train..."

(The interjection of the editorial 'said this witness' may have been well advised: according to the terms of the 1869 Nitroglycerine Act only 5 cwt. (203 kg) could legally be conveyed at one time).

The second of the two Scottish railways which would carry dynamite may have been the North British Railway. The N.B.R. transported the mercury fulminate which the British Dynamite Company bought in to make detonators at its two Stirlingshire factories: that at Polmont and another at West Quarter. It seems unlikely that the line would have been given the carriage of the fulminate without agreeing to carry dynamite without prejudice.

The ability of the railway companies to monitor what freight was carried on their lines was limited to the information entered on way-bills and marked on cases. Referring again to the article cited above, there is a grim humour in some of the testimony relating to the ways in which the prohibition against the carriage of dynamite on the railways was circumvented:

"The Duke of Sutherland gave favourable evidence respecting the transport and use of dynamite, he having practical experience in both those respects. When referring to the difficulty of getting it transported by rail, and on being asked how he had effected its carriage, his grace simply observed that hatboxes were very convenient and portable..."

The efforts of bootlegging noblemen aside, the railway's sustained refusal to carry dynamite was probably more of a sore annoyance than a direct restraint upon the extent to which dynamite was used in the United Kingdom after 1873. Water transport - both coastal and inland - was adequate to bring dynamite to within easy reach of most of the hard-rock mining districts where it was used.

The Shipment of Dynamite by Sea

If the carriage of dynamite by rail was so beset by difficulty and by restrictions, then at least there were fewer problems associated

with water transport. The Ardeer factory had access to the small port of Irvine for the shipment of its production. Indeed it seems certain that without this outlet the Ardeer factory could hardly have operated at all. Export cargoes posed few problems:

"Mr. Jones of the firm of Jones, Scott & Co., Shipping Agents, as to the great demand for these compounds in Australia, to which country he had shipped ... a large quantity of dynamite, and where there were comparatively no restrictions as to its transport..."

Engineering, 12th June 1874

And again, a year later, an example which will serve to say something not only of the scale of production at Ardeer, but also something of the level of the export trade in explosives from a major United Kingdom port at that time.

"Shipments of Explosives . - Every now and then a large shipment of dynamite is made from Irvine or from the British Dynamite Company's works direct at Ardeer. The last shipment was made a few days since; it was a cargo of forty tons for Peel and Whitehaven. The vessel in which it was carried was insured for 3,000 pounds, the company also paying the sum of 85 pounds as freight, port charges, pilotage, etc... Most unnecessary excitement has occasionally shown itself at Irvine in connection with the loading of dynamite. From the Firth of Clyde last month there were shipped 189,700 lb. (86 tonnes) of gunpowder, making for the past nine months 1,512,500 lb. (665 tonnes). The amount shipped for the corresponding nine months of 1871 and 1872 was considerably greater, but whether or not the falling off of the shipment is due to the increased consumption of dynamite I am unable to say. The thousandth toncharge was made a few weeks ago, and formed into dynamite, and worked up into cart-ridges ready for blasting purposes, in mining and quarrying operations."

Engineering, 29th October 1875 (p.34)

Dynamite as a Rival to Gunpowder and other Explosives

Once in production and freely available, the merits of dynamite were quickly appreciated. The following will give some idea of the rate at which dynamite overhauled other explosives in those areas where it did offer distinct advantages. The following is a part of the evidence given by Dr. C. Le N. Forest (Inspector of the Western District: Somersetshire and Dorset) before H.M. Commissioners and Inspectors on Mining Accidents and the Employment of Explosives in Mines ... 1868 - 1881, Mining Accidents 10 (p.129), 27th May 1879.*

"4114. The use of dynamite is nevertheless very much increased within the last years ? - Very much so. I have some statistics on the point from eighteen mines during the last six years. These eighteen mines employ 3,144 persons underground, or 38 per cent of the persons employed underground in my district. So they may be taken as a very fair representation, and they include all my mines. And I find from the statistics supplied to me by the managers of these mines that in 1873 those eighteen consumed 19,159 pounds (8.4 tonnes) of dynamite, whereas in 1878 they employed 88,922 pounds (39 tonnes) of dynamite. The use had increased more than fourfold in 1878.

4115. And can you give us the figures with reference to the quantities of gunpowder and other explosives? - I have gunpowder, dynamite, lithofracteur, and gun-cotton. In 1873 these 18 mines consumed 217,389 pounds (97 tonnes of powder; in 1874, 225,301 pounds (99 tonnes); in 1875, 210,423 pounds (92.5 tonnes); in 1876, 191,536 pounds (84 tonnes); in 1877, 174,932 pounds (77 tonnes); in 1878, 140,869 pounds (62 tonnes).

4116. That is gunpowder? - Yes.

4117. And of the other explosives? - Tonite, none used until 1875...

4119. Then at present it is only dynamite which at all rivals the gunpowder as an explosive? Yes..."

* Irish University Press: 10 (Mining Accidents), British Parliamentary Papers, Shannon: Ireland.

It can be supposed that as Inspector of the Western District the witness would be chiefly concerned with metalliferous mines.

CHAPTER 12

PICRIC ACID AND THE PICRATE EXPLOSIVES

(1867 - 1875)

Introduction

It has been found difficult to treat picric acid without reference to picrate explosives; it has been as difficult to discuss picrate explosives without frequent reference to picric acid. Much of the material consulted is common to both. The main problem has been one of allocating emphasis. The use of the picrate explosives between 1867 and 1885 is a small but important part of the history of explosives. It is a distinct and discrete area, in many ways an isolated part, of the history of the introduction of the high explosives. Picric acid did not truly come into its own until some ten years after the period of the present study. But the story of its development up to and beyond 1875 lies behind that of the picrates, because they were derived from it; and eventually, when the potential of picric acid was realised, they were replaced by their own parent explosive. Picric acid will be discussed first.

Picric acid was known and used long before its explosive properties were suspected. Its history as an organic dye-stuff cannot be discussed further here than to note that between 1771 when Woulfe prepared it by treating silk with nitric acid and 1843 the French chemist, Laurent, prepared an identical substance by nitrating the inorganic substances phenol and dinitrophenol, the compound was re-discovered several times.

The compound also had a separate identity as a flavouring. The Chemical Gazette of 1st August 1857 (p.242) contains an article by J. Otto in which it is pointed out that Dumoulin had recommended picric acid as a substitute for hops. The detection of the illicit use of

picric acid in beer was achieved by leaving a strip of white woolen yarn in the suspect beer for twenty-four hours.

The Manufacture of Picric Acid and the Picrates

No very special apparatus was needed to make picric acid. The production of the picrates required only the addition of a simple treatment. The operation in both cases was considered to be generally 'safe'. The technology for making picric acid had been worked out well in advance of its application as an explosive because the substance had long been used as a dyestuff. All that was needed was a large increase in the overall scale of the manufacture.

Disappointingly little detail of the production process followed before 1875 can be offered here. There is an abundance of material dealing with the manufacture of all the aromatic hydrocarbons after 1885 in Colver's (1918) text.* Oscar Guttman, who is usually fullsome in his provision of illustrative engravings, does not offer a single plate in his (1893) encyclopaedic work to show anything of the manufacture.

Two processes were in use. In both, because of the alarming violence of the reaction which occurred when it was attempted to nitrate the phenol directly, it was the practice to treat the phenol first with sulphuric acid alone, to produce phenol-sulphuric acid. This operation was carried out in iron vessels: at that stage there was no danger of the sensitive ferrous picrate being formed. The iron vessels were fitted with stirring gear and heated by means of steam jackets. Sulphonation was adjudged complete when the resulting syrup was found to dissolve fully in cold water.

A novel method of nitrating the sulphonated phenol is described by Guttman. Since he specifically prefixes his single sentence of

* High Explosives (A Practical Treatise), by Captain E. de W.S. Colver Dr. Met. F.C.S. etc. (London, 1918).

reference with the word 'Formerly', it might be supposed that he was writing of a process that had not been in use for a number of years.

"Formerly nitrating was also done in another manner - namely by bringing the phenol-sulphuric acid in contact with sodium nitrate, when nitric acid was formed, which at once reacted upon the phenol. In this process sodium sulphate was obtained as a residue..."

When the manufacture of picric acid went over to a large scale after 1885 the nitration was carried out directly with nitric acid. The sulphonated phenol was cooled, diluted with twice its volume of water, and allowed to run slowly into earthenware vessels charged with nitric acid of 1.400 specific gravity. The reaction which accompanies this stage was said by Guttman still to be very violent, giving rise to great quantities of nitric acid vapour.

The process was notably economical because waste acids which had already been used for the nitration of cotton or glycerine could be used for the nitration of phenol without producing an inferior product.

The purification of the nitrated phenol was achieved by a process of successive re-crystallisation. The insolubility of picric acid in cold water, and its solubility in hot water, made this a relatively simple process.

The manufacture of the principally used picrates was also a cheap and easy process. Potassium picrate was made by adding picric acid dissolved in hot water to a hot solution of potassium carbonate. The yellow crystals of potassium picrate separated out on cooling. Ammonium picrate, the picrate adopted for use with the British services because of its stability, was made by treating picric acid in hot solution with concentrated ammonia solution.

The Limitations of Picric Explosives

From the beginning, explosives based upon picric acid were recognised as having little civilian application. The reason for this severe limitation lay in the chemical constitution of picric acid. The known deficiency of oxygen produced a reaction during its explosion which gave off quantities of carbon monoxide, oxides of nitrogen, and hydrocyanic acid. In addition, and most particularly when in later years picric acid was used alone, there often remained after an explosion much heavy yellow coloured vapour - unconsumed picric acid - which tended to hang on still air for a long time afterwards. Major J.R. Cundill, writing of the year 1889,^{*} describes how some French soldiers who had been set to digging shell fragments out of the ground were poisoned by picric acid vapour remaining in the camouflet left by the explosion of the bursting charge. Such explosives clearly could not be used in mining or in civil engineering.

The physiological effects of exposure to picric acid - a staining of the skin and often a dermatitis - must have been well known from an observation of the complaints of workers in dye factories long before the compound was used as an explosive.

The picric acid based explosives had no special qualities which might have attracted commercial interest. By the mid 1860's there were many other explosives in production and being marketed by companies that had already taken the first steps towards becoming cartels. Messrs. Curtis & Harvey is perhaps the best example of this. Much capital was already invested in explosives manufacture. Picric explosives would have had to have been launched against very strong market competition. The American Civil War had created a demand which had led to an over-production of explosives, particularly of blackpowder, which was to leave

^{*} A Dictionary of Explosives, by Major J.P. Cundill, H.M. Inspector of Explosives (London, 1893).

a surplus which was not to be dispersed from almost fifteen years afterwards.

Picric Explosives in Military Use

The limitations to the use of picric explosives in civilian works would apply equally to cognate military operations - to military mining and demolitions.

There thus remained an extremely narrow field of possible use for the new picric explosives when they were introduced. There had, however, been a curiously neat collocation of invention and military need which was to provide a quite specific use for these explosives.

Armstrong had introduced his breech-loading, rifled, fieldgun in 1861. This allowed for rapid rates of fire and for a great extension of both range and accuracy. To make optimum use of this invention an efficient explosive shell was needed.

There are certain essential requirements for a satisfactory bursting charge for shells. And this was very well understood at the time. The picrate powders had just the qualities required and were thus able to fill a peculiar technological niche for a number of years.

The shell-filling had to be powerful - but not too rapid in its action. An article in the French journal, Bulletin Mensuel, which was published in translation in The Engineer of 26th January 1872 (p.55) shows an appreciation of the problem. The article from which the information comes describes the shift made by the authorities in the besieged city of Paris to provide their forces with explosives during the war of 1870-71.

"There are two principal conditions attached to the bursting of a shell, the fulfilment of which can alone ensure its success in a destructive point of view: one is that the shell should be shattered into as many fragments as possible, and

the other is that those should be scattered in every direction to as great a distance as the charge will allow..."

The proportion of the volume of a shell projectile which can be filled with explosive is limited, not by weight, for an increase in weight in a shell without an increase in volume would be accounted an advantage, but rather by the power of the explosive being used as a bursting charge. Only so much explosive can be packed into the shell. Too much of the shell's volume devoted to the bursting charge would have to be paid for by having a less dense shell which would not fly so far nor so accurately as one that is more compact. Gunpowder was too weak an explosive to be efficient as a bursting charge; gun-cotton was powerful but not sufficiently insensitive, it was also too sudden in its action; dynamite was also too sudden and of course too sensitive. The picrate explosives and picric acid were the best available explosives for shell filling.

The Long Delay in discovering Picric Acid's Explosive Qualities

It was undoubtedly the extremely stable nature of picric acid which made it more than usually likely that its explosive properties would have been discovered until theoretical chemistry had advanced sufficiently far for the compound's explosive potential to be indicated, almost as a 'solution by inspection', by someone noticing the similarity between its formula and those of other known explosives.

Had the discovery of picric acid's properties to have waited upon the occurrence of an unlikely accident they would not have been discovered until 1887. On 22nd June of that year there was a devastating blast at the factory of Messrs. Roberts & Dale, at Cornbrook near Manchester. The investigating committee under Colonel V. Majendie was able to show that molten picric acid had detonated when it had come into contact with litharge.

Exactly when and by whom the explosive nature of picric acid was discovered - or even fully suspected - is uncertain. Some main articulations for the story can, however, be posited.

Laurent put forward a formula for picric acid in 1843. But it is observed that in 1843 none of the other high explosives were generally known; there was, therefore, little opportunity for making comparisons between formulae, and hence for making inductive leaps towards predictions about the compound's behaviour.

At some time between 1843 and 1869 the similarities between the molecular structure of picric acid and that of other compounds was noticed. This is the area of most uncertainty.

It is here pointed out that picric acid, more than any of the other high explosives coming into use during the middle part of the century, depended absolutely upon the invention of the mercury fulminate detonating cap. Both gun-cotton and nitroglycerine were used for some years without the fulminate detonator. Its introduction made a working practice very much more efficient; it was not a necessary condition for their use. Without mercury fulminate, picric acid might long have been considered a chemical curiosity: its formula giving rise to an expectation that it would be a powerful explosive, its manifest behaviour presenting a disappointing failure to react in the way expected.

The magazine Engineering for 9th April 1869 (p.242) provides the first reference found for this study which makes extensive mention of picric acid. The occasion for the article was said to be the then recent disaster of a serious explosion in Paris. The explosive concerned had been Fontaine's powder, a mixture of picrate of potassium and potassium chlorate, not* picric acid. But the main value of the

*Engineering, 27th October 1871 (p.262)

article lies in the following:

"Laurent ... who proved it (picric acid) to be carboic acid in which three atoms of hydrogen have been replaced by three atoms of the group number 2. This constitution at once explains the explosive character of the acid and its salts. It will be seen that the oxygen, of which there is a large quantity, is nearly all combined with nitrogen. Now compounds of oxygen and nitrogen are very easily decomposed, especially in the presence of substances having a very powerful attraction for oxygen, such as carbon and nitrogen..."

The article reveals something of the state of chemical knowledge in 1869. The significant statement in the article is:

"This constitution at once explains the explosive character of the acid and its salts."

So in 1869 the explosive nature of the pure picric acid was known by at least one writer. And yet fully two years later, in 1871, the man who was responsible for the successful development of ammonium picrate explosives, Frederick Augustus Abel, was to state in the Chemical News for 15th September 1871 (p.150), in an article much published and quoted elsewhere:

"The acid itself does not explode, but burns quickly with a bright flame; its salts are all more or less powerfully explosive and detonate when struck..."

On Recent Investigations and
Applications of Explosive Agents
by F.A. Abel, F.R.S.

That same year, Dr. Herman Sprengel, F.R.S. is said to have detonated a charge of pure picric acid at the factory of Messrs. Hall and Sons, at Stowmarket. He was not encouraged to continue his work by any support from the Ordnance Department.

In the specification of one of his patents

(Probably^{*}) English patent No.2642 of 5.10.71, Sprengle states, though apparently as an afterthought to engross the compound within his specification, for it relates sensibly in no way to the rest of the text, 'I also use picric acid'.

To quote much from the work of Herman Sprengel would be to anticipate a later section, but the following is felt to be more especially relevant to the present topic.

"It is noted here that picric acid alone contains a sufficient quantity of available oxygen without the addition of any foreign oxygen carrier for it to be an extremely powerful explosive, provided it is ignited by means of a detonator; on explosion practically no smoke is developed."

It may have been this deficiency of oxygen atoms in the deduced structure of picric acid which led some workers, notably F.A. Abel, to suppose that the deficiency was such as to preclude an explosive reaction.

There is a small disagreement over the primacy of discovery of picric acid's susceptibility to detonation. Colver (1918) comments on an assertion made by Daniel in his work, Dictionnaire des Matieres Explosives, Paris 1902, that Sprengle's work was purely theoretical, and that the actual discoverer was the Frenchman, Eugene Turpin. No evidence for either view is offered here except to comment upon Sprengle's own words: 'practically no smoke is developed'.

Now, all sources consulted have remarked upon the smoke which is evolved during the explosion of pure picric acid. The explanation may be that, as Sprengle himself observes, a detonator was essential. If Sprengel had used a substantial detonator with a relatively small charge of picric acid the result may have been a very thorough reaction which entirely consumed any smoke or vapour.

^{*}(Colver (1918) dates the patent 2.10.71; Cundill dates it 5.10.71. The difference is probably trivial but it is recorded).

Where Sprengle could have come upon his discovery that pure picric acid was susceptible to detonation was during the work which led up to the publication of his 1873 paper. If he had been, while working at Hall & Sons' factory in 1871, making a systematic examination of the reactions of various hydrocarbons with various oxidising agents, it is reasonable to suppose that he might have studied the effects of increasingly greater proportions of the oxidising agents - starting, for the sake of experimental rigour, with a sample which contained no oxidising agent at all.

The worst that Sprengel may have been guilty of was making a general statement about a phenomenon he had observed, perhaps, only on a single occasion.

The general recognition that picric acid could be used alone in its pure state without the addition of oxidising agents did not come until 1885 when Eugene Turpin took out British patent No.15,089. In its eventual and most efficient form picric acid was melted and cast into varnished shell casings. The inherent insensitivity of the compound was overcome by interposing a booster of powdered picric acid between the solid mass of the main charge and the fulminate cap.

An Early Picric Acid Powder

An explosive suggested by Borlettino in France, during or some little time before 1869, constitutes a single instance of picric acid being used in a mixture with oxidising agents prior to the discovery of Sprengel Explosives in 1873. No reference to any parallel instance in U.K. practice has been found in any source consulted.

The explosive is often mentioned in general works on explosives, but there would appear to be a lack of any certain knowledge of its actual composition. Cundill (1893) states that Borlinetto used ten

parts of pure picric acid, ten parts of sodium nitrate, and eight and one half parts of chromate of potassium; Colver (1918) gives the same formula with respect to the picric acid and the sodium nitrate but has it that Borlinetto used chlorate of potassium. Both men were considerable authorities in their times so it is unlikely that they were unable to detect glaring errors in the information they used in compiling their works. It is allowed that chlorate and chromate might be mistaken in the transposition from handwriting to type. In the formula given by Colver, it seems unlikely that a double proportion of oxidising agents would have been used - sodium nitrate and potassium chlorate would have given rise to an excess of oxygen. Cundill's assertion that eight and one half parts of chromate of potassium has in its favour the more certain fact that various chromates were used later in the century when trinitrotoluene explosives came into wide use. The principal source for Cundill's entries concerning continental explosives was Desortiaux' translation of the works of Drs. O. Upmann and E. von Meyer: Traite sur la poudre, le corps explosives, et la pyrotechnie. This work may have been more authoritative on Continental practice.

Ammonium Picrate

Frederick Augustus Abel, F.R.S. was the chemist most active in developing the use of this explosive for military purposes. Abel invented a mixture of ammonium picrate and potassium nitrate in the proportions of 60: 40 to which he gave the name 'picric powder'. It was in this form - so far as can be discovered, alone - that ammonium picrate was employed in the British services.

Abel describes his invention in the journal Chemical News for 15th September 1871 (p.150). As the inventor he had reasonable cause to be enthusiastic about his picric powder. His description of its

qualities are almost lyrical. And, when the properties and limitations of all the other explosives available at that time are reviewed, it might well be allowed that Abel's picrate powder answered its special purpose very well.

"The picric compound may be readily prepared on a large scale ... when heated over a flame it fuses, sublimes, and burns without any tendency to explosion... it is difficult to obtain evidence of detonation when the ammonium salt is struck sharply and repeatedly... exhibits no tendency towards ignition when submitted to very severe friction ... is quite equal in permanence to gunpowder ... may safely be submitted to the pressing and granulating process ... the cost of the picric acid, when compared to its powder, is not considerable."

On Abel's assertion about the cost, there is a clear contradiction by Cundill: 'It is stable, safe to manufacture and handle, but rather expensive.' He is referring to Brugere's Powder which was virtually identical to Abel's picric powder.

To be efficient as a shell-filling an explosive had to be able to withstand the heat and the sudden shock of the propelling charge and the immediate impact of striking the target. In an account of experiments carried out at Shoeburyness during June of 1871, it is stated that he (F.A. Abel) had used a 49 lb. (19.3 kg) 'battering charge' in a nine inch (23 cm.) calibre gun. A battering charge was the heavy propelling charge used to attain the maximum impact when a shell struck home. It was usually employed against standing fortifications. This indicates that Abel was testing the resistance of ammonium picrate (picric powder) to premature explosion in the barrel of the gun. Ammonium picrate, in its picric powder form, was available as a shell-filling explosive to British artillery and naval ordnance from about 1870

until beyond 1885. It was, however, a time of general peace. Picric powder may in reality have seen very little actual use at all during those years.

Potassium Picrate

Explosives based upon potassium picrate were not adopted for any purpose at all in the United Kingdom. Some use was for a time made of potassium picrate in the French services, in the form of Designolle's Powder. But this was abandoned because of the instability of the mixture. Designolle's explosive contained potassium chlorate as an oxidising agent.

The only reference to a potassium picrate found comes from an article which appeared in the Magazine Engineering for 9th April, 1869 (p.242).

"The first to make practical application of this property of picrite of potassium was Mr. Whitworth who used the salt to fill shells to be directed against the armour plating of ships."

The picrates were, then, early in use as a part of the projectile versus armour plate competition which went on until the 1930's of the present century.

The Special Position of Picric Acid

Picric acid stands in a special position in the history of the military use of explosives. Phenol was the first material which could be used to make a cheap, stable, solid, high explosive for which there was a supply of the prime material without active limit. It was inorganic. All the other materials which had been used to make explosives before phenol - cotton, glycerin, starch, and the like - were subject to a 'guns or butter' limitation. Organic materials had

alternate uses which were pressing and immediate. The supply was unpredictable for more than a year ahead; it depended upon the allocation of the limited areas of cultivable soil. But the use of phenol made no inroads into the supply of food and clothing of the civil population. The solution of the problems associated with the large scale production of sulphuric acid and nitrates which was to be found by the turn of the century would have been of no avail without the utilisation of the inorganic hydrocarbons derived from coal. Phenol was the first of these to be used for making explosives. Picric acid made the sustained artillery barrage of explosive shells possible.

Notes

1. The magazine Engineering for 16th February 1872 contains an article which describes work done by Leygue and Champion in France. Experiment showed that picrates were, in general, better able to withstand heat than either mercury fulminate or mixtures of chlorate and sulphur: 315° C. - to - 380° for picrates against 200° for the fulminate and the chlorate mixture.
2. There can be few explosives which have been known by so many different names as picric acid:

trinitrophenol, trinitro-carbolic, carbazotic acid, picranzic acid, crysoleptic acid, and, in later years when a more descriptive nomenclature had been worked out, tri-nitrohydroxyl-benzine.
3. The resin from which picric acid was said to have been made before it was discovered that it could be made from phenol is in some places rendered as Xanthorrhoea hastilis, in others as Xanthorrhoea saxtilis.
4. The article which appeared in the journal Engineering of 9th April 1869, and which has been so useful in compiling this section, attributes the contents of the article to Lancet. A most careful

survey of Lancet for the five years preceding 1869 has failed to turn up the original article under any heading which might apply to picric acid.

CHAPTER 13

THE SPRENGEL EXPLOSIVES

(1873 - 1875)

Explosives compounded upon the principles put forward by Dr. Herman Sprengel, F.R.S. in his patents, British patent No.921 of 6th April 1871 and No.2642 of 5th October 1871, have received more general attention than their real contribution merits.

Sprengel explosives are almost invariably mentioned in articles offering to cover the topic of 'Explosives' in general, those articles of the kind which can be found in technical dictionaries and encyclopedias of any date from the seventies of last century up to the present. The contents of such articles are so remarkably alike, so limited in extent, that it is hard not to suspect that the material has been derived directly from a single source. And, in researching the sources for this particular topic, this has been found to be the case. The single and most extensive account of Sprengel's work with explosive substances is his own paper: "XXXII - On a New Class of Explosives which are Non-explosive during their Manufacture, Storage and Transport (p.797 et seq), which was read before the Chemical Society and published in the J.C.S. for August and September of 1873.

The 1873 paper was a thesis of chemical findings as much as an announcement of discoveries in explosives technology.

Sprengel's Table

The full extent of Sprengel's experiments with explosives is best demonstrated by referring to the table of compounds which he included in his paper. This table, as can be seen, was designed to provide a survey of what Sprengel termed 'oxygen compounds' and to show the

theoretical total proportion of oxygen in a given compound, followed by an estimation of the quantity of that proportion which was capable of being released for explosive interaction.

Name	Formula	Total O in 100	Available O in 100
Peroxide of hydrogen	H_2O_2	94.1	47.0
Water	H_2O	88.8	-
Nitric Acid	HNO_3	76.2	63.5
Nitric anhydride	N_2O_5	74.0	74.0
Carbonic acid	CO_2	72.7	-
Peroxide of lithium?	Li_2O_2	71.1	35.5
Oxalic acid	$H_2C_2O_4$	71.1	-
Nitric peroxide	NO_2	69.5	69.5
Tetranitromethane	$C(NO_2)_4$	65.3	65.3
Sulphuric acid	H_2SO_4	65.3	?
Perchloric acid	$HClO_4$	63.6	55.7
Trinitroglycerin	$C_3H_5(NO_2)_3O_3$	63.4	42.3?
Nitrate of ammonia	NH_4NO_3	60.0	50.0?
Gun cotton	$C_6H_7(NO_2)_3O_5$	59.3	32.3?
Nitrate of sodium	$NaNO_3$	56.4	47.0
Trinitroacetoneitril	$C_2(NO_2)_2N$	54.5	54.5
Peroxide of acetyl	$C_4H_6O_4$	54.2	13.5?
Acetic acid	$C_2H_4O_2$	53.3	?
Glycerin	$C_3H_8O_3$	52.2	?
Silica	SiO_2	51.9	-
Nitrate of urea	$H_4N_2CO_2HNO_3$	51.4	32.5
Cellulose	$C_6H_{10}O_5$	49.4	?
Picric acid	$C_6H_3(NO_2)_3O$	48.9	41.9
Nitrate of potassium	$KaNO_3$	47.5	39.6
Chlorate of potassium	$KaClO_3$	39.2	39.2
Cyanic acid	$CNHO$	37.2	?
Cyanuric acid	$C_3N_3H_3O_3$		
Cyamelide	$C_nN_nH_nO_n$		
Fulminuric acid	$C_3H_3N_3O_3$		
Peroxide of manganese	MnO_2	36.7	18.3
Nitrate of diazobenzene	$C_6H_4N_2HNO_3$	28.7	23.9

Nitrobenzene	$C_6H_5(NO_2)$	26.2	26.2
Iodic acid	I_2O_5	23.9	23.9
Phenol	C_6H_6O	17.1	?
Fulminating mercury	$C_2Hg(NO_2)N$	11.2	11.2
Charcoal	$C_mH_nO_p$	10.0	?

It should be said that Sprengel did not claim that his table was complete. He is most careful to point out that 'the total amount of oxygen in a compound is by no means a criterion of the amount available for combustion'.

What might be said to be the broad hope which lay behind the entire series of experiments can be deduced from the last sentence of the paragraph containing the table (p.799; lines 8 - 14):

"If the explosion of gun-cotton and nitroglycerine is merely the sudden combustion of carbon and hydrogen at the expense of the oxygen supplied by three molecules of nitric peroxide, mixtures may be formed which contain (with reference to the foregoing table) more oxygen than these powerful explosives, and therefore ought to surpass them in effect."

It is not too much to say that Herman Sprengel was looking to discover, or more properly to prove the existence of, compounds which he had in effect postulated to exist. And in keeping with this, his work was methodical and very wide in its range.

Sprengel did not discover any hitherto unsuspected and superlatively powerful cognates to gun-cotton or nitroglycerine. But the chemical corollaries, the easy inferences which would have had to have been looked at at some time before the end of the nineteenth century, were examined.

The Small Scale of Sprengel's Work

So far as can be determined from a close reading of Sprengel's 1873 paper, the scale of work upon which he bases his report is small. The explosive compounds were detonated in 'an open wide-mouthed glass-bottle, containing from 20 to 100 grams at a time'. Only once, when describing his experiments with potassium chlorate (see below) does Sprengel give any indication that his work went outside of the laboratory. The reason for a small scale of operation can be appreciated. When the number of combinations tried is considered, it can be seen that any larger scale of work would have been prohibitively expensive. Only those few compositions which showed promise in the laboratory would warrant a more extensive trial.

It may be this smallness of the scale of Sprengel's experiments which attracted the claim later made by Daniel (See Picric Acid) that the experiments were mere theoretical essays.

Picric Acid

For all the later controversy over Herman Sprengel's claim to be first to have discovered that picric acid, used alone without the aid of any additional oxidising agents, could be detonated, it is the case that he devotes very little space indeed to picric acid in the text of his 1873 paper. He repeats with little amplification the statement which he had inserted in an incongruent way into the specification of his British patent No.2642 of 5th April 1871.

"Be it noticed that picric acid alone contains a sufficient amount of oxygen to render it, without the help of foreign oxidisers, a powerful explosive when fired with a detonator..."

If Sprengel thought the discovery to be of any great moment at that time, he fails to indicate the fact by anything he records in his paper.

The mixing of picric acid with strong nitric acid resulted in an unexpected reduction in temperature: 'the glass soon became frosted...'. Nevertheless, the mixture exploded with great violence when fired with a detonator.

The excess of oxygen in the combination (52.29 per cent) which was considered to be 'available for combustion' is simply noted.

Nothing more can justifiably be said of picric acid and its place in Sprengel's work than that it was one of a number of 'combustible' substances which Sprengel combined with his 'oxidisers'. Within the wide range of the experiments carried out, picric acid was mentioned - but it appears not to have been thought exceptional. As will be suggested presently, picric acid attracted some retrospective attention for reasons not directly connected with its chemical properties.

Nitroglycerine

A calculated theoretical excess of oxygen (3.52 per cent) in the composition of nitroglycerine was to be utilised by combining the explosive with a small percentage of either naphthalene or picric acid. Here, again, Sprengel refers the reader to his British patent No.4642 of 15th October 1871.

Also, he advocates the dissolving of 'an organic base, such as aniline', into nitroglycerine, partly for the same reason as that above but also, and more informatively, for the 'purpose of neutralising any acid that may be generated by a slow decomposition'. This statement indicates that Sprengel, as late as 1871, held much the same view of the chemical composition and properties of nitroglycerine as that which had been entertained by Sobrero twenty-five years earlier - that it was 'only a question of a longer or a short time before they began to decompose with the production of nitrogen dioxide.'

See Nitroglycerine

Nitric Acid

Of the many compounds suggested by Sprengel as oxidising agents, nitric acid presented some special technical problems in both handling and use. This particular compound is singled out for discussion here because it is felt that it did have at least a potential for practical application as an explosive under certain conditions, though those necessary conditions could not easily have been met at the time Sprengel published his paper.

The other oxidisers used by Sprengel also had difficulties and dangers attached to their use. But these were only those already known and partly met when these chemicals had been used, earlier and elsewhere, as explosives in their own right: the deliquescence of ammonium nitrate, the capricious sensitivity of potassium chlorate and nitroglycerine, and so on.

Nitric acid, used in the way Sprengel recommended, was, so far as can be determined, a new oxidiser. There were other compounds which might have been used in the same way. Nitric Peroxide (Nitrogen Peroxide NO_2) with its tantalising estimated 69.5 per cent of oxygen theoretically available for explosive combination was an outstanding example. Only nitric acid, however, was to be had cheaply and in the quantities which would have been needed to supply any extensive use.

It is reasonable to speculate that had not so many safe, stable, and powerful explosives been discovered at about the same time, Sprengel's mixtures of one or more of the aromatic hydrocarbons with strong nitric acid could well have enjoyed some use in blasting. The technical problems which would have had to have been overcome would have been different in kind from those which had to be met when, say, nitroglycerine was introduced, but they could not have been of a much greater magnitude.

Corrosiveness is less to be feared than explosiveness. The problems were those of containment and manipulation; they were derived from the limitations of the materials which were then available for the handling of dangerous substances.

The mixture was a liquid; it would have needed to have been very securely contained in a cartridge. Any spillage at all would have rendered further handling extremely dangerous. The only material which might have made an acid-proof cartridge case and which is sufficiently robust for general use is lead foil or thin sheeting. Sprengel indicates that he had already anticipated a source of difficulty here. A cartridge had to be filled; it had also to be fitted with a blasting cap and the end of a Bickford fuse or the wires from a battery of cells. It was found that the use of the nitric acid oxidiser called for an especially strong blasting cap - ten grains (0.65 gram) of mercury fulminate, as against the six and one half grains (0.46 grams) which was commonly used. Also, he used 'that form of percussion cap which has been described in Messrs. Abel and Brown's patent' (See Mercury Fulminate). This kind of blasting cap contained the mercury fulminate in a seamed tin tube plugged with a little loose gun-cotton. Obviously, there was a need to protect the fulminate and any fuse from the acid. It will be recalled that E.C. Howard had seriously injured himself when he had poured nitric acid onto mercury fulminate. There was also the need to seal the point at which the fuse or leads entered the cartridge.

In order to overcome all of these problems, Sprengel placed the capped end of his fuse into a 'thin glass tube ten centimetres long'. This appears to have worked. But this was, of course, in the laboratory situation where small quantities of the explosive mixtures were being fired off by men who had a good idea of what they were about, and who

were working in full daylight. It cannot be supposed that a length of glass tube was a reliable protection under any other than these specialised conditions. A strong union between glass and metals is a relatively recent achievement.

A second prohibitive difficulty came from the very great heat generated during the explosive reaction. Sprengel found that a brass container had become melted and that some grains of sand had fused together after a test explosion. Under such conditions a soft metal foil could well have volatilised to give off poisonous fumes - this would have made the use of such mixtures underground extremely dangerous.

It was more because of problems such as those outlined above that little further use was made of the nitric acid based explosives proposed by Herman Sprengel.

In-situ preparation often requires some specialised apparatus. Only where the project is very large and a great quantity of explosives is to be used can the expense of such preparation be justified. The real distinction between in-situ preparation and the setting up of a small local 'factory' may be small. Given that some means could be found to contain the explosive, there seems to be no reason why it should not have found an application. Much of the Simplon Tunnel was blasted with liquid oxygen explosives - this must have presented at least as many problems as nitric acid explosives.

Potassium Chlorate

The last of the compounds which Sprengel discusses at any length in his paper is potassium chlorate. There is a note of dissatisfaction in the first sentence of this part of the work:

"Relinquishing the attempts to obtain total gasification we return again to explosives which are nearly related to common gunpowder, as their oxidising agents are salts with a non-volatile base."

As might be supposed, Sprengel was able to record that potassium chlorate 'furnishes detonating explosives when mixed with almost any organic substance'. To avoid the more obvious dangers associated with the use of potassium chlorate, he worked with 'combustible liquids, which when brought into contact with porous cakes or lumps of potassium chlorate are absorbed quietly and without risk.' The cakes of potassium chlorate were made by pressing finely powdered, slightly moistened, chlorate into moulds. These dried cakes were said to possess 'the porosity of lump sugar'. Sprengel states also that the porosity of the cakes depended upon the fineness of the powder used and the degree of compression. This may have been so. But common sense would indicate that such cakes would not long retain their cohesion when soaked with a liquid, especially with a liquid of low specific gravity, even where they pressed to the 137 kg. per square centimetre needed to compact the 'press-cake' in gunpowder manufacture. The machinery which presents itself as being most readily available for the purpose in the 1870's is that used by pharmacists for compressing pills, or by the confectioners for making bon-bons. Hand presses are well able to compact crystalline powders into cakes of reasonable durability. The suggestion is made because of Sprengel's mention of 'moulds' and because of what has already been observed about the small scale of Sprengel's experiments.

The use of the chlorate in the form of such cakes would at least have ensured that the liquid hydrocarbons used would reach all parts of the cartridge when the charge was made active.

The combustible liquids which Sprengel tried with the chlorate oxidiser included carbon bisulphide, petroleum, naphthalene, benzine, and nitro-benzine; some of these were tried in combination, and with or without a small addition of sulphur. All were found to be more or less explosive when absorbed into the chlorate.

A mixture of potassium chlorate and benzine without any addition of sulphur resisted detonation until a more powerful cap was used.

Carbon bisulphide with potassium chlorate was proved to be about four times as effective as gunpowder:

"Such a mixture, used in open granite quarries for blasting, proved to be about four times as effective as the same weight of gunpowder."

The above is the only mention of practical trials made with any one of the Sprengel explosives in the entire paper. There is, unfortunately, no supporting detail. When burned in the open air, chlorate cakes soaked in 'combustible liquid' did not explode.

Sprengel concludes his discussion of his work with potassium chlorate by engrossing - without giving any account of practical experiments carried out - several other solid oxidisers:

"As in the acid mixtures so here, a great many mutations are possible. Potassium chlorate may be partly (or perhaps totally) replaced by potassium nitrate - or sodium nitrate."

Ammonium Nitrate

Discussion of ammonium nitrate occurs relatively early in Sprengel's paper. However, because ammonium nitrate came eventually to more extensive use than almost any other of the compounds proposed by Sprengel, it has been held over to last. It provides a point of

exit which leads most directly to modern explosives technology.

Only some twenty lines of Sprengel's paper are devoted to his work with nitrate of ammonia. He observes that oxidising agents which afford 'perfect gasification' are few, but almost at once he excludes ammonium nitrate from the list on the grounds of its great affinity for atmospheric moisture.

Sprengel's work with ammonium nitrate must properly be considered to have been a deviation from the main aim of his experiments, which was to discover new blasting agents. The whole of the paragraph which deals with what Sprengel had actually done with the nitrate of ammonia describes his efforts to increase the initial velocity of small arms projectiles by adding to ordinary sporting gunpowder a mixture of ammonium nitrate with 7.5 per cent of lamp black.*

There is nothing in what Herman Sprengel wrote in his paper concerning ammonium nitrate which would allow any claim at all to be made for him to be named as the inventor or discoverer of any explosives based upon ammonium nitrate. But it is precisely such explosives which have come to be among the most widely used of the modern general purpose explosives. Only in as much as the constituents may be mixed immediately before use can an explosive making ammonium nitrate as its oxidising agent be classed as a 'Sprengel' explosive; the salt was not, so far as the 1873 paper records events, one of the oxidisers Sprengel used in his experiments with blasting compositions.

* Here, and ironically where he was straying from the main course of his experimental work, Herman Sprengel had under his hand a practical blasting explosive, had the problem of the salt's deliquescence been overcome:

"Known in that country (U.S.A.) as Akremite, the composition of which is given as 100 parts ammonium nitrate with 6 parts carbon black, it is claimed to give very economical blasting."

British Coal Mining Explosives, James Taylor & P.F. Gay, Pub. Geo. Newnes Ltd., London, 1958, (p.150).

The reason why Sprengel quickly abandoned nitrate of ammonia was, as has been said, its rapid deliquescence. He saw that it would have some potential if 'air-tight cartridges' could be found. We have already seen how the limitations to the level of development in container technology was a source of difficulty in the application of nitroglycerine. In order to have used ammonium nitrate a means would have had to have been available to protect it absolutely from the air. And here again there were few options - the tinned canister representing the most likely.

It was not until the fifties of the present century that a container efficient enough and cheap enough to carry large quantities of deliquescent salts. The container was the now ubiquitous polythene sack.

It is the polythene sack which has made possible the easy maintenance of ammonium nitrate in its dry crystalline form. It is the wide availability of ammonium nitrate in this form which has allowed the coming into being of a special class of explosives. The cause and effect chain appears to be direct.

ANFO, 'Ammonium Nitrate - Fuel Oil' explosives have come into extensive use since the 1950's, especially in those countries which do not have strict explosives legislation (ANFO explosives cannot legally be compounded or used in the U.K.).

ANFO charges are made simply by damping ammonium nitrate with a little fuel oil: diesel fuel. As an explosive ANFO is quite powerful, it is reliable and it is stable. It must be something of a jest in the history of technology that the great chemical industries, the descendants of the explosives manufacturers of last century, should have set up distribution systems on an international scale for the supply of ammonium nitrate fertiliser; that similar systems have been set up for the supply of fuel oil; that these two, brought together, allow the

compounding of a fair substitute for many proprietary explosives at a small fraction of their cost.

In the end, then, explosives have come to be made in the way envisaged and advocated by Herman Sprengel (and to be fair, independently by the American, S.R. Divine). But the oxidising agent was to be one he had fully rejected for use, and the 'combustible' was one he is unlikely to have known of.

(Intuitively, it can be supposed that the invention of explosives of the ANFO type owed nothing at all to Sprengel, or indeed to any other chemist. Proprietary explosives consisting of a salt and a hydrocarbon can be analysed by inspection and smell, and a little chemical knowledge of a very elementary level. The discovery that an explosive can be made from ingredients to be found in the environment might be held to show that there are, in the so-called Third World, men working at a genuinely empirical level of chemical technology and making discoveries, quite independently, which are of great local utility).

Later 'Sprengel' Explosives

Sprengel's 1873 paper attracted remarkably little attention in the journals of the day. Those journals which ordinarily could be expected to report quite trivial advances in explosives technology - Engineering, The Engineer, Journal of the Chemical Society - hardly mention Sprengel's work. Even the Journal of the Society of Chemical Industry, in which the paper was originally published, does not devote further space to it. Nor is there any reason why this should be otherwise - Sprengel had acknowledged the grave deficiencies in his projected range of explosives himself at the end of his paper.

Writing of Sprengel's experiments in 1872, before the publication of the paper in the J.S.C.I., F.A. Abel's comments are measured rather

than enthusiastic:

"It remains to be seen whether mixtures of this class can be applied with advantage as substitutes for violent explosive agents which are now rapidly supplanting gunpowder in some of its important uses."

No.1342 - "Explosive Agents Applied to Industrial Purposes by Frederick Augustus Abel, F.R.S., Institute of Civil Engineers, Vol. XLV., London, 1872 (p.351).

It was not until after 1882 when Turpin, in Paris, had announced the introduction of his invention 'Panclostite' that Sprengel was to be reminded of his earlier work. He did not respond at once. It was not until some four years later that an article under his name, 'Note on So-called Panclostite', appeared in the Journal of the Society of Chemical Industry for the 29th April 1886 (p.200).

Sprengel was able to refer to his original paper and show where he had anticipated the Frenchman, and for the most part he is justified in his assertions.

But Sprengel was not the first person to have been angered by Turpin's claims. It was F.A. Abel who almost three years earlier, in his Presidential Address to the annual meeting of the J.S.C.I. on 11th July 1883, had already attacked Turpin's claims with some scorn. With so much snarling over a so long abandoned bone, it is hard not to suspect that the motivation was one of raw nationalism. Sprengel devotes almost half of his 1886 article to quoting Abel, who had already made many of the same points of argument which Sprengel was to reiterate. The general tone of Abel's attack can be judged from the following:

"The publication in France of researches or inventions as original, the results of which have long been published in England, is an occurrence to which we are not unaccustomed, and so the performances of Sprengel's offspring, furnished by Mr. Turpin with an impressive family name..."

It seems appropriate here, in the interests of balance, to give a translation of as much as is to hand of Turpin's specification. This is taken from Note on So-called "Panclastite" cited above. It is noted that neither Herman Sprengel nor the J.S.C.I. thought fit to offer Turpin's claims in an English translation. Moreover, that which is given is clearly selected material.

In "Notice sur la Panclastie, etc. 'par' Eugene Turpin, Paris, E. Bernard & Cie, 1882," we read:-

P.11 - "PANCLASTITE (Brise tout;- de: av, tout; k aw, je brise). Explosifs à base de peroxyde d'azote.

"Principe découvert par Eug. Turpin (1878 à 1882).

"Le corps comburant est le peroxyde d'azote pur et anhydre à l'état liquide.

"Cette section a cela de tout à fait remarquable, c'est qu'aucun des produits qui entrent dans la composition des nombreux explosifs qui en font partie n'a jamais été employé à la confection d'un autre mélange détonant. Le comburant ou les combustibles n'ont jamais été appliqués, en aucun cas, dans ce but, soit ensemble, soit séparément, tandis que dans les 1re, 2e et 4e sections on retrouve le soufre et le charbon.

"Recherchant de suite toute ce que pouvait lui donner la découverte de ce nouveau principe, M. Turpin est parvenu à produire plus de cent explosifs nouveaux, c'est-à-dire un nombre plus considérable que celui qui comprend tous les explosifs connus antérieurement."

P.5 - "La Panclastite est dans ce dernier cas. Découverte par M. Eugène Turpin, elle constitue une invention de principe qu'il ne faut pas confondre avec une invention reposant sur des principes connus, ce qui est le cas de la dynamite; les inventions de principe

sont extrêmement rares et tendent à diminuer encore au fur et à mesure que le progrès se développe, tandis que les inventions d'application ou de perfectionnement augmentent constamment."

Translation

"An explosive with a nitrogen peroxide base. The principle was discovered by Eugene Turpin between 1878 and 1882. The oxidiser is pure anhydrous nitrogen peroxide in the liquid state.

This section is quite remarkable in that none of the chemicals which compose the numerous explosives which are part of it has previously been employed in the manufacture of any other explosive.

The combustibles have previously been applied in any case for this purpose, whether together or separately, whereas in the first, second and fourth section one can find sulphur and carbon.

Seeking immediately what the discovery of this new principle might give him, M. Turpin has managed to produce more than a hundred new explosives, that is to say, a greater number than all the explosives hitherto known.

P5. 'Panclastite' is in this last category. Discovered by M.E. Turpin, it constitutes an advance in theory which must not be confused with an invention based upon a known principle, as is the case with dynamite. Advances in theory are extremely rare, and tend to become more so as progress develops, whereas inventions deriving from application or improvement are increasing all the time."

It may well be, then, that the term Sprengel Explosives came to be used, at least in the English-speaking world, for no more worthy reason than that it was thought to be politically desirable that the work of Sprengel should be given a not entirely deserved prominence during the 1880s when Anglo-French relations were less than cordial.

In the event, both claimants may fairly be said to have been anticipated in respect of a single explosive of the 'Sprengel' type, if judged by its composition alone. The most detailed description of this explosive is to be found in a footnote to the chapter dealing with

Sprengel type explosives in Cundill's Dictionary of Explosives:

"Mr. Silas R. Divine, U.S.A. claims to have invented a mixture of chlorate of potash and nitro-benzole (now termed Rack-a-rock) and on the 9th January 1871, he filed a caveat in the confidential archives of the United States Patent Office, but published no patent till 1880."

The following short list gives the registered names of explosives coming into use after 1875 which could be said to be Sprengel type explosives: Hellhofite, 1880; Oxonite, 1883; Bellite, 1885. None of these explosives could be used in the United Kingdom since they could not meet the safety criteria required for inclusion on the 'Permitted List'.

CHAPTER 14

AMMONIUM NITRATE EXPLOSIVES

Introductory Note

The ammonium nitrate explosives have practically speaking little place at all in any account of the development of explosives in the United Kingdom before 1875. The first generally used explosive based upon ammonium nitrate was Amide Powder (British patent No. 14,412 of 24th November 1885) which was introduced as a 'safety' mining explosive.

The reason for including what little information there is on explosives of this class is that they later became enormously important, both as safety mining explosives for use in gassy coalmines and, far and away above any other use, as military explosives. Any history of the use of explosives between 1885 and the present would have to devote a great deal of space to the ammonium nitrate explosives. It was thought to be appropriate, therefore, to locate this kind of explosive in its proper time, even if this meant showing how little important it was before that time.

Ammonium Nitrate Explosives

Powders containing any material proportion of nitrate of ammonia did not come into extensive general use until the introduction of the Amide Powders after 1885. Nevertheless, the potential of nitrate of ammonia was long appreciated and there were a number of attempts at applying the salt as the oxidising agent in explosives during the nineteenth century. Indeed Oscar Guttman in his book Twenty Years Progress in Explosives^{*} gives the following reference to ammonium nitrate:

"This also (ammonium nitrate) was tried in France in the eighteenth century with but little result."

^{*}'The Manufacture of Explosives, Twenty years Progress', Guttman, O., Whittaker, London, 1912.

He cites: Bottee et Riffault, "Traité de l'art de fabriquer la poudre à canon." (A Treatise on the art of making Gunpowder and Cannon), Paris, 1811.

Nitrate of ammonia probably became freely available when sulphate of ammonia derived from the 'ammoniable water' by-product of gas-works presented a ready source. The salt was produced by way of a double decomposition of sulphate of ammonia with nitrate of potassium, in solution with water. The difference in the temperatures of crystallisation allowed an easy separation of the two newly formed salts: sulphate of potassium and nitrate of ammonia.

In his work, A Handbook of Chemical Technology, the German chemist, Rudolf Wagner, makes the following observation:

"... the fact that when strongly heated it is converted into protoxide of nitrogen and steam ($\text{N}_2\text{O} + 2\text{H}_2\text{O}$) might perhaps render it of use in the preparation of a blasting powder."

The conjecture would have been a truly inspired one if it had been included in Wagner's 1850 edition; it merits progressively less praise if it was inserted into any of the further six editions which were printed between 1850 and 1870; if it was an addition to the eighth edition, Wagner was sadly behindhand. Unfortunately, there has been no opportunity to inspect any editions other than the eighth, of 1872.

The most extensive treatment of ammonium nitrate explosives found appeared in the Journal Engineering for 3rd September 1869 (p.157). The article was derived from foreign sources.

"A NEW EXPLOSIVE MATERIAL - The following account of a new explosive material is abridged from Kolnische Zeitung, May 19th, which gives the Militär-Wochen-blatt as its authority:-

It is now some time since the proprietors of the Nora-Gyttorp Powder Mills obtained a patent in Sweden for the discovery

of the so-called 'ammonia powder', a substance which has hitherto only been employed in a few mining districts, but which otherwise seems wholly unknown. Its explosive force may be compared with that of nitroglycerine, and, consequently far surpasses that of dynamite. It cannot be exploded by flame or by sparks, and the explosion can be effected by a heavy blow from a hammer. Blast holes loaded with this powder are exploded by means of a powerful cap, or, better, by means of a cartridge containing common powder, for this forms a more reliable exploder. One of the more important properties of this new powder is, that it does not require heating in cold weather, whilst nitroglycerine and dynamite must first of all be warmed, and this has been the cause of many accidents."

The same paper further adds:-

"According to information we have received, ammonia powder was discovered by the chemist Norrobin." *

The German Building News contains extracts from a report of the Prussian Architect, Steenke, who makes the following remarks upon the safety of ammonia powder:-

"Experiments were made by fastening a lamp pendulum, which was caused to oscillate; gunpowder, gun-cotton, nitroglycerine, and dynamite all took fire as the flame passed over them, but the ammonia powder did not begin to burn till it had been touched by the flame twenty times ... a fall of from 12 to 15 feet (3.66 m - 4.6 m) was necessary to cause the explosion of ammonia powder."

Ohlsson and Norrobin's explosive was ammonium nitrate mixed with about 10 per cent of charcoal, or sawdust; ** they also were able to induce detonation in pure ammonium nitrate crystals alone by using a strong blasting cap (or, as was mentioned in the quotation from Engineering cited above, by the use of an initiator of black gunpowder).

The overriding objection to the use of ammonium nitrate in explosives was the salts great affinity for water - exposed to the air it quickly deliquesced to a wet paste.

* C.J. Ohlsson & J.H. Norrobin: Swedish patent granted 31st May 1867.

** Explosives, A. Marshall, Pub. Churchill, London, 1917 (p.36).

APPENDIX I

MINOR AND LITTLE KNOWN EXPLOSIVES

This appendix is a collection of information about those explosive compositions which were patented in the United Kingdom before 1875. It represents the residuum of material which, although very interesting in itself, could not justify separate topic headings. The main thread upon which the information is strung is, as will readily be seen, those headings in Cundill's Dictionary of Explosives which indicate an explosive used in the United Kingdom during the period under study. To this has been added any material which extends the bare outline given by Major Cundill.

The list of compositions is probably far from exhaustive, but it is felt that it will go some way to filling the many spaces which perforce have had to be left when the main topics were treated. If nothing else, it affords a starting place for further studies.

The compositions are arranged in order of the given dates for the granting of the patents.

<u>NAME OF POWDER</u>	<u>DATE OF PATENT</u>	<u>BRITISH PATENT NUMBER</u>
MELVILLE'S POWDER	6th October 1850	13,215

NOTES & COMMENTS

Mentioned only in Cundill's dictionary, this powder is notable for the early date of its invention and for the apparent absence of any directly organic substances in its composition. Cundill gives the formula as follows:

"Chlorate of potash, 5 parts; red orpiment,^{*} prussiate of potash, 1 part."

* Red orpiment: Cundill probably was referring to realgar, red arsenate, (As₂S₂); orpiment was ordinarily the name for Auri pigmentum, yellow sulphuret of arsenic (As₂S₃).

<u>NAME OF POWDER</u>	<u>DATE OF PATENT</u>	<u>BRITISH PATENT NUMBER</u>
MACINTOSH (proposed)	11th February 1852	404

NOTES & COMMENTS

Cundill gives the following description:

"Macintosh proposed to mix gunpowder and other explosives with india rubber or guttapercha in a state of solution, and to spread the mixture on cloth, which became inflammable, burning rapidly if mixed with chlorate or nitrate of potash, and slowly if mixed with steel filings or sulphur. The cloth can be cut into strips and used in connection with incendiary projectiles."

<u>NAME OF POWDER</u>	<u>DATE OF PATENT</u>	<u>BRITISH PATENT NUMBER</u>
SCHLESINGER'S POWDER	20th July 1852	14,227

NOTES & COMMENTS

Cundill gives the formula:

"Chlorate of potash, 3 parts; sulphide of antimony,
3 parts; flowers of sulphur, 1 parts."

The only comment Cundill makes about this composition is that it was proposed for use in small arms. The mixture is essentially a form of white gunpowder. It is suggested that any free sulphurous acid from the flowers of sulphur could have reacted with the chlorate to produce spontaneous ignition-explosions.

<u>NAME OF EXPLOSIVE</u>	<u>DATE OF PATENT</u>	<u>BRITISH PATENT NUMBER</u>
KOHLER'S POWDER	10th June 1857	1,622

This was a simple chlorate gunpowder - see the main text dealing with chlorate explosives.

<u>NAME OF EXPLOSIVE</u>	<u>DATE OF PATENT</u>	<u>BRITISH PATENT NUMBER</u>
DAVIES' POWDER	30th March 1860	824

NOTES & COMMENTS

The following information about the above was given in the journal, The Engineer, for 12th October 1860.

"824. J. Davies and G. Payne, Truro "Gunpowder - Dated 30th March 1860."

"This invention relates to the manufacture of a white gunpowder by the use and mixing together of certain ingredients in proportions which the patentees have found to answer well in practice. They use the following materials in the proportions attached to each respectively, viz, yellow prussiate of potassium, $\frac{1}{4}$ lb. (113 grams), chloride^{*} of potassium, $\frac{1}{2}$ lb. (226 grams) loaf sugar, 2 oz (56 grams), crystallised sugar, 2 oz. (56 grams), and brimstone, 1 oz. (28 grams). These materials, when finely pounded and mixed together, produce a white gunpowder which has many advantages over the gunpowder at present in use, it being quicker and more powerful in its action..."

This powder is noted in Cundill's dictionary.

*The misprinting, mis-spelling, or simple mistaking of one chemical name for another occurs quite regularly in the literature. In the above clearly chlorate not chloride was intended.

<u>NAME OF EXPLOSIVE</u>	<u>DATE OF PATENT</u>	<u>BRITISH PATENT NUMBER</u>
HARRISON'S POWDERS	29th October 1860	2,642

NOTES & COMMENTS

Cundill gives the following formula for this powder:

"Chlorate of Potash, 7 parts; starch, 1 part; charcoal, 1 part, sulphur, 1 part; clubmoss* (lycopodium clavatum); and (alternatively) coal, 1 part, or, soot from coal, $\frac{1}{2}$ part."

*Lycopodium powder is the collected spores of clubmoss. It is in the form of a yellow powder, much like powdered resin, and it is inflammable.

See Harrison's 1861 patent

<u>NAME OF EXPLOSIVE</u>	<u>DATE OF PATENT</u>	<u>BRITISH PATENT NUMBER</u>
HARRISON'S POWDERS	6th September 1861 (And) 5th February 1862	2,233 305

NOTES & COMMENTS

Unlike Harrison's 1860 patent (No.2,642), the above were essentially 'white' gunpowders. Cundill gives the following formula:

"Chlorate of potash, 56 parts; ferrocyanide of potash, 28 parts; starch, 4 parts; sulphur, 7 parts; charcoal, 5 parts; alternative ingredients, cannell, or, coal, or saltpetre.

<u>NAME OF POWDER</u>	<u>DATE OF PATENT</u>	<u>BRITISH PATENT NUMBER</u>
KELLOW'S POWDER	17th June 1862	1,796

Cundill classifies this powder as a chlorate explosive - probably because it was so classified under the Explosives Act. However, since the formula contains a very much greater proportion of potassium nitrate, it will be treated in the section of the present work which deals with nitrate explosives other than gunpowder.

<u>NAMES OF EXPLOSIVE</u>	<u>DATE OF PATENT</u>	<u>BRITISH PATENT NUMBER</u>
RICKER'S POWDERS	9th December 1862	3,297
<u>Probably alias</u>	and	<u>and</u>
SPENCE'S POWDER	10th April 1863	949

NOTES & COMMENTS

In Cundill's dictionary the reference SPENCE gives simply the direction: see RICKER. The heading RICKER gives the following:

"Ricker's Powders (note the plurality) consist of ten varieties of chlorate mixture containing a number of substances in addition to the chlorate of potash, such as charcoal, half calcined sea-grass, powdered coal, sawdust, nitrates of soda, lead, or potash, wheat flour, bicarbonate, powdered bark and dried coffee grounds. The ingredients are all boiled together in water."

A paragraph in the 'Patents Received' section of The Engineer for 10th April 1863 gives the following:

"W. Spence, Chancery Lane, London, 'Manufacture of Gunpowder', - A communication. - dated 15th April 1863.

The first kind of powder made according to this invention, and which is suitable for ordnance, is composed of the following ingredients, in about the following proportions, and the process is as follows:- The patentee puts into a cooking or other similar vessel thirty eight parts in weight of water, and two parts in weight of finely pulverised charcoal, which are to be thoroughly boiled together; he then adds twenty parts in weight of chlorate of potash, and six parts in weight of a mixture (hereinafter to be referred to as the mixture A) and stirs it until the whole is thoroughly mixed. By this addition the boiling is interrupted, and, therefore the whole mixture must be brought again into a boiling state. After this there is added seven parts in weight of fine, well-sifted, and thoroughly dried sawdust or pulverised bark, and the boiling is continued until the wood is thoroughly saturated, and becomes part of the mixture. The mixture A referred to above consists of two parts in weight of finely pulverised coal and from three to four parts of bicarbonate of soda, or nitrate of lead or saltpetre, or their chemical

equivalents. The requisite evaporation or drying of the mixture may be effected by means of open pans to which steam is applied, and the granulating process is the same as usual."

(From the address given for the above patent it is very likely that the SPENCE of the specification was a patent agent acting for RICKER. Chancery Lane occurs often in the journals as the address of persons taking out patents.

Ricker was from all appearances a determined eccentric. The Engineer for 10th July 1863 carries in its 'Patents Received' section a specification(497) submitted by a Mr. M.F. Benton of Percy Street, Bedford Square, London, which is similar to the one given above in so many respects that it is hard not to conclude that it was not one of Ricker's essays. The submission is , however, marked Not proceeded with.

<u>NAME OF POWDER</u>	<u>DATE OF PATENT</u>	<u>BRITISH PATENT NUMBER</u>
HOCHSTÄTTER'S COMPOUND	17th December 1862	2,233

NOTES & COMMENTS

Cundill gives the following information:

"Hochstätter's Compound consists of a mixture of chlorate of potash or of lead, nitrate of potash or of soda, and charcoal or sulphur, or a metallic sulphide. The mixture is dissolved in water, in which paper or vegetable matters are steeped so as to render them explosive."

The discussion which followed the presentation of Abel's 1872 paper: "Explosive Agents applied to Industrial Purposes," contained the following passing reference to Hochstätter's invention:

"A few of comparatively safe character had been produced as blasting agents, and to some extent used; among these were ... and also a material obtained by the saturation and coating of bibulous paper with a mixture of chlorate of potash, charcoal, and other oxidisable substances, first devised by Hochstätter for use in small arms, and recently proposed by Reichen for blasting purposes."

Proceedings of the Institution of
Civil Engineers, Session 1872-73,
Part I, Vol. XXXV (p.1).

<u>NAME OF EXPLOSIVE</u>	<u>DATE OF PATENT</u>	<u>BRITISH PATENT NUMBER</u>
HALL'S POWDER	28th April 1863	1,062

NOTES & COMMENTS

The following information about the above was given in the journal, The Engineer, for 11th December 1863.

"This invention consists in producing an explosive compound for general purposes of the following ingredients, the same being slightly modified according to requirements - say, in the proportion of 100: - The patentees take 47 parts of chloride^{*} of potassa, 38 parts of ferrocyanide of potassium, together with about 5 parts of sulphur, or other chemical, such as refined sugar, which they have found to be preferable from two causes - first, it is less detonating or liable to explode from mere friction; and, secondly, more perfectly explosive, leaving no deposit or fouling. They reduce these ingredients separately to a powder by grinding in a suitable mill or otherwise, and when the ingredients are properly ground, they are to be thoroughly mixed, adding water, or nitric acid diluted with water, which increases the strength, imparting to the compound a bluish-green colour, and is readily taken up and incorporated with the other ingredients, to permit the whole to be formed into a stiff paste; afterwards they allow the composition thus prepared to stand, allowing the water to evaporate, and then they add 10 parts of caoutchouc^{**}, slightly incorporated with bisulphide of carbon, which has the effect of destroying any impurity in the general compound, so that there shall be less residue after the explosion. These ingredients should be thoroughly mixed one with the other, and if to be used in the form of powder must be pressed and then granulated; fine or coarse, as preferred, or according to the purpose for which they may be required to be used."

* chlorate

** Raw 'India Rubber'

<u>NAME OF EXPLOSIVE</u>	<u>DATE OF PATENT</u>	<u>BRITISH PATENT NUMBER</u>
EHRHARDT'S POWDERS	8th July 1864	1,694
	(And)	
	20th October 1864	2,594
	(And)	
	13th February 1865	402

NOTES & COMMENTS

In modern parlance Ehrhardt's powders would be described as a 'systems' explosive; the composition was varied to produce an explosive for many differing uses: artillery, blasting, shells. A typical formula in Cundill for one of Ehrhardt's blasting chlorate powders is chlorate of potash, one part; saltpetre, one part; charcoal, four parts; tannic acid, two parts.

The similarity between the powders patented by Ehrhardt and those patented by J. Horsley is noted. The Engineer for 11th February 1869 (The article: On Explosive Compounds for Engineering Purposes by Mr. Perry F. Nursey) contains the following sentence:

"Of this class is Ehrhardt's powder, the invention of which is also claimed by Mr. Horsley."

Ehrhardt may have taken out his patent for an improved gunpowder to counteract Horsley's claim. The Engineer for 8th September 1865 gives the following in its 'Patents Received' section:

"402. L.H.G. EHRHARDT, Richmond Road, Bayswater, 'Improved Gunpowder' - dated 13th February 1865.

The patentee claims the use of tannin, or such substances as contain this material in large proportions, such as catechu* and gum* kino, artificial tannin, coal, or other description of mineral, carbon, wood charcoal, or other vegetable carbon. He claims the use of any one or more of the above ingredients in combination with either chlorate of potash, or other fusible chlorates, or nitrate of potash, singly or in combination, and for the manufacture of gunpowder."

* Both catechu and gum kino were used as tanning agents. Wagner's Chemical Technology 8th Edn. 1870 (Tr. W. Crookes F.R.S.) devotes some space to a consideration of such tannin-containing substances.

<u>NAME OF POWDER</u>	<u>DATE OF PATENT</u>	<u>BRITISH PATENT NUMBER</u>
NISSER'S POWDER	26th July 1865	1,939

Cundill gives the following formula for this powder which was designed to be used for blasting and, with an increase in the potassium salts included, as an ordnance powder.

"Yellow prussiate of potash	1.5
Bichromate of potash	2.0
Perchlorate of chlorate of potash	10.5
Nitrate of Soda and Potash	44.5
Vegetable matter	6.5
Mineral and Vegetable carbon	19.5
Sulphur	15.5

Again it is observed that Cundill classified any powders containing a small percentage of the chlorate of potassium as a chlorate explosive because they were so classified by the Explosives Act of 1875. All explosives containing chlorate were rightly regarded as being sufficiently dangerous to warrant the special classification.

<u>NAME OF EXPLOSIVE</u>	<u>DATE OF PATENT</u>	<u>BRITISH PATENT NUMBER</u>
SHARP'S POWDER	27th October 1866	2779

NOTES & COMMENTS

Cundill gives the formula:

"Chlorate of potash, 2 parts; saltpetre, 2 parts;
yellow prussiate of potash, 1 part; potash⁴², 1 part;
sulphur, 2 parts."

No other information is available.

*'Potash' generally can be taken to mean potassium carbonate derived from wood-ashes when used in nineteenth century chemical technology texts.

<u>NAME OF POWDER</u>	<u>DATE OF PATENT</u>	<u>BRITISH PATENT NUMBER</u>
HAHN'S POWDER	30th March 1867	960

NOTES & COMMENTS

Cundill gives the formula:

"Chlorate of potash, 367.5 parts; Tersulphide of antimony, 168.3 parts; spermaceti,* 46 parts; charcoal, 18 parts."

He also comments:

"The idea is to add the chlorate of potash only when required for use, the mixing being done by sieves. The addition of spermaceti is claimed to give safety against explosion by friction."

*Spermaceti is the white solid wax-like substance taken from the head of the Sperm-whale. It was much used for good quality candles during the last century.

<u>NAME OF POWDER</u>	<u>DATE OF PATENT</u>	<u>BRITISH PATENT NUMBER</u>
PERTUISET'S POWDER	9th October 1867	2,837
	(And)	
	21st July 1870	2,066

NOTES & COMMENTS

Pertuiset's powder is classified here as a chlorate gunpowder; but it is observed that the content of carbon was so small that the compound should really be considered as a simple two-to-one mixture of chlorate and sulphur. Cundill gives the following formula:

"Potassium chlorate, 2 parts; sulphur, 1 part;
sporting gunpowder, 1/8th part; animal charcoal, 1/50th part."

Of itself, Pertuiset's powder was not novel, nor could it be said to have been particularly successful in any technical sense; but incidentally to the development of explosives it did have a small but significant effect upon the course of the political history of the times.

Very considerable anti-French sentiment was aroused in England shortly before the outbreak of the Franco-Prussian War by newspaper reports of a hideous experiment in which live cavalry horses - some hundreds at a time, in close tethered masses - had been used as targets for rapid mitrailleuse fire using explosive bullets. Pertuiset's Powder was the filling used in these explosive bullets. Engineering for 27th October 1871 devotes a few neutrally objective column inches to the effects of Pertuiset's powder in bullets:

"... the shattering effects were fully developed upon the skulls, ribs and legs of the unfortunate targets. The results were communicated to the English Government, but we believe that they refused to recognise the material..."

F.A. Abel gives a brief mention of Pertuiset's power in explosive

bullets in his 1871 paper:*

"By converting the mixture into a paste and then drying it, hard masses of the explosive agent can be produced, which are made to fit shells of lead, and afterwards completely enclosed in the metal by the operation of 'spinning'.

*
Professor Abel on Explosive Agents.
On Recent Investigations and Applications of Explosive Agents
by F.A. Abel, F.R.S. Chemical News, 15th September 1871 (p.126).

<u>NAME OF EXPLOSIVE</u>	<u>DATE OF PATENT</u>	<u>BRITISH PATENT NUMBER</u>
HORSLEY'S POWDER	19th April 1869	1,193
	(And)	
	22nd June 1872	1,885

See main text

<u>NAME OF POWDER</u>	<u>DATE OF PATENT</u>	<u>BRITISH PATENT NUMBER</u>
ROGERS' COMPOSITION	12th April 1870	1,356

NOTES & COMMENTS

Cundill gives the formula:

"Chlorate of potash, 5 parts; cascarilla bark,* 2 parts; corondum, 3 parts; India rubber solution, 3 parts."

He also comments:

"... for making blasting fuzes. The object of the corondum, or other non-inflammable ingredient, is to retard and regulate the burning. The compound was to be dipped in bisulphide of carbon, benzine, or other solvent, to mix it. The solvent was then evaporated, and the mass was ready for making coils or strands."

Cascarillia bark was a pharmaceutical substance: a source of the purgative croton.

NAME OF POWDER

DATE OF PATENT

BRITISH PATENT NUMBER

PUDROLITHE

PUDROLYTHE

2nd March 1872

656

ROCK POWDER

NOTES & COMMENTS

Cundill gives the following formula for this powder:

"Saltpetre, 68 parts; sulphur, 12 parts (alternatively sulphur 8 parts with 3 parts of gumlac); charcoal, 6 parts; nitrate of baryta, 3 parts; nitrate of soda, 3 parts; sawdust, 5 parts; spent tan, 3 parts."

He also supplies the following information:

"The nitrates of soda and baryta are dissolved in hot water and the tan and sawdust added to the solution and boiled until dry. The other ingredients are then added, and the whole mixed together. The compound claims to be slow burning, and to give but little smoke.

The manufacture of this explosive was carried on at a factory near Llangollen, but was abandoned a few years ago."

Mr. R.S. France, a quarry proprietor, contributed a few remarks of commendation about the explosive to the discussion which followed upon the reading of F.A. Abel's 1872 paper "Explosive Agents applied to Industrial Purposes" which was read before the Institution of Civil Engineers.

"There was one other explosive he had been using for the last month, called 'pudrolythe'. It was a simple-looking substance, but it was a remarkably good explosive, better than gunpowder, gun-cotton, dynamite, or litho-fracteur, or any other explosive he had used, under certain circumstances; but those circumstances were so exceptional, that it was difficult to use it to any great extent. If a hole, perfectly tight, and sunk in very hard rock, could be ensured, with no chance of any of the material escaping, then pudrolythe was the safest and best explosive, because it had not the tendency that gun-cotton and nitro-glycerine possessed of shattering particular classes of stone."

And again, this time in a contribution by a T. Mason, in the same discussion.

"... a brief history of the manufacture and use of a new explosive called 'pudrolythe'. The advantages claimed for it were, that it was safe when surrounded by the atmosphere, and, unless tightly tamped, would not explode; that it was considerably cheaper and one third more powerful than gunpowder, and that the system of manufacture was easy; and that there was, comparatively, an absence of smoke on explosion; that water would not spoil it - for when dried on a hot plate, it was just as good as it was previous to being wetted; and that no deleterious gases were emitted by the explosion. He was confirmed in these statements, by certificates from distinguished Belgian chemists and engineers, and in Belgium there was no hesitation on the part of railway managers to its transport as ordinary traffic. It had received the approval of Mr. Hayward of Carnarvon, where the dynamite explosion had taken place, who stated that he considered pudrolythe was the best explosive yet introduced. Mr. Mason had witnessed numerous experiments with it by Mr. George Farren, Assoc. Inst. C.E., the manager of the Welsh Granite Company, the results of which he submitted to the Meeting. Understanding that the powder he had first received had been made some time ago, he thought it might possibly require keeping to improve with age, and with the view of testing this question he arranged it in four distinct parcels, for experiment, on different kinds of rocks, at Lord Ponrhyn's quarries, and he found that within fifteen minutes after mixing the compound it exploded a charge ... It was used in the same way as ordinary blasting powder, and the charge was rammed down with an iron bar, as pudrolythe would not explode by fire from flint and steel, nor by concussion. It might be struck on an anvil without exploding. As compared with ordinary blasting powder, only two-thirds the quantity of pudrolythe would be required..."

F.A. Abel himself observed that:

"Pudrolythe appeared to be an old acquaintance under a new name. He had some years ago to report upon a site near Plymouth, where it was proposed to manufacture a blasting powder,

composed of spent tan mixed and impregnated with nitrate of potash and sprinkled with sulphur. It was comparatively harmless if inflamed when exposed to the open air, but in a good blast-hole was said to do very fair work. This preparation, known as 'Kellow's powder' was so far safe to manufacture, that the works were burnt down twice without explosion. It appeared to him that pudrolythe was, in point of fact, this old material revived under a new name, with this difference, that a little nitrate of baryta and a little sawdust and charcoal powder were added. He would suggest to powder-makers that they might possibly make the old blasting powder compete with pudrolythe, if they were to use imperfectly burned charcoal, and either to supply the powder ingredients only roughly mixed, or to sell them separately, to be mixed as required... He must say that the statement that pudrolythe evolved no deleterious gases when exploded was to him startling in its originality."

<u>NAME OF POWDER</u>	<u>DATE OF PATENT</u>	<u>BRITISH PATENT NUMBER</u>
FENTON'S POWDER	17th 1873	4,148

There is a misprint in Cundill's dictionary
for this entry: '22'.

NOTES & COMMENTS

Cundill gives the following information:

"Fenton's powder consists of chlorate of potash, sugar, and yellow prussiate of potash in the proportions of four to eight ounces (.2268 kg) of each of the latter ingredients to sixteen ounces, (.4536 kg) of damp chlorate. The mixture is made in the form of a stiff dough, being dampened with lime water, gum-water, or water. It is dried in an oven, cut up with brass knives, and sifted into various sizes of grains. The powder can be coloured with various colouring matters, which it apparently proposed also to use in lieu of sugar. It is claimed as suitable for all kinds of small-arms and ordnance and for blasting purposes."

<u>NAME OF EXPLOSIVE</u>	<u>DATE OF PATENT</u>	<u>BRITISH PATENT NUMBER</u>
SAFETY BLASTING POWDER (also known as) CARBO-AZOTINE	14th November 1874	3,934

Cundill gives the following information:

"Safety Blasting Powder is licensed for manufacture in this country by Messrs. Pigou, Wilks and Laurence (Ltd.). In the licence it is defined as a mechanical mixture of saltpetre, sulphur, lampblack, sawdust, and sulphate of iron. In the specification it is defined as consisting of:-

Nitrate of Potash

"	" Soda	one, two, or	50 to 64 parts
"	" Lime	three nitrates	

Sulphur	13 to 16 parts
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Tanner's bark (That containing refuse animal matter is preferred) or

14 to 16 parts

Sawdust, or

Bark and Sawdust

9 to 18 parts

Soot or Lampblack, or both

and 5 to 6 parts of sulphate of iron to every 100 parts of the above mixture.

The materials are ground and boiled in a weak solution of sulphate of iron. The compound becomes liquid and then generally solidifies. When nearly solid it is dried.

This powder is issued occasionally in bulk, but more usually in the form of compressed cartridges like those made of gunpowder. It requires compression and confinement before it will explode.

It is recommended to be used as a wash, with about 10 gallons (45.5 litres) of water to 2 lbs. (907 grams) of the compound as a remedy for phylloxera vastatrix (?)."

The Continental equivalent of Safety Blasting Powder was CAHUC's Powder.

Oscar Guttman devotes some paragraphs to 'Carboazotine of Raymond Cahuc' in his book The Manufacture of Explosives, Whittaker & Co., London 1895 (Vol.I, p.272-273). He gives it as an example of 'a method long known to the Tartars.' The ingredients were mixed to a

paste with water and heated while being stirred continuously. Of the properties of Safety Blasting Powder Guttman says:

"This powder has a very slow rate of combustion, but develops large quantities of gas. It has been used on a large scale in chamber mines for blasting operations at the Iron Gates on the Danube. Its use is advantageous in certain coal mines, because it does not shatter the coal."

(Of powders made by the boiling process, Guttman comments that they are never perfectly mixed because the saltpetre separates out as large crystals when the mixture is cooled; the sulphur also separates to form small nodules which sink to the bottom of the mixing pan. Both of these occurred even when stirring was continuous).

FOR APPENDIX II

SEE ENCLOSURE WALLET
INSIDE BACK COVER

CONCLUSIONS

The progress made in all aspects of explosives, science and technology, after 1845 was only a small sector along a front of advance in the applied sciences generally which was unprecedented for its speed and its extent. The making of explosives is a branch of applied chemistry. What can - in the round - be said of applied chemistry can be said of Explosives. However, what can be said of applied chemistry has in large measure already been said elsewhere. It can only be profitable here to try to point out in which particulars the history of explosives differs or deviates materially from the main stream of development in other branches of applied chemistry and chemical technology.

Contributions to the discovery of new explosives by British chemists during the nineteenth century were negligible. After the work of C.E. Howard at the beginning of the nineteenth century, there are no British names in the forefront of original discovery and invention in the field of explosives. British chemical ingenuity in, for example, dyes, was not present in work on explosives. This is a statement of fact, not a judgement; invention and discovery are unique events. It was a time when there were rather more exciting avenues of chemical research opening up than there were properly trained chemists to enter them. In a sense it could be said that the explosives had to compete for the attention of the chemists and did not do well.

The main British contribution to advances in explosives was in the development of invention: in the raising of finance, the setting up of factories and plant, in the refinement of processes, and in the provision of undertakings which would use the finished product in large quantities.

Britain may have been a better prospect for the setting up of a civilian factory than other European countries. Between 1815 and 1880 the country was only in one full-blown war: the Crimean War. It was a time of relative peace. In Europe the enmities of the eighteenth century continued. A probable course of action for the inventor of an explosive was to seek support from his own country's military, first. Both Schönbein and Nobel had done this. The second step was to 'carpet-bag' across Europe to secure, first of all, local legal protection for the invention and secondly, to demonstrate the explosive to government representatives. A military adoption usually brings immediate financial return. An immediate financial return was desirable to individual inventors because they would naturally wish to retain control over their own invention. Again, Nobel and Schönbein were to enter into unhappy financial arrangements. London was the centre of a colonial empire rather than of the usual European hegemonies. The British Empire was in the process of exploiting its overseas possessions. The main instruments of the exploitation were the railways and mining activity. Both were to use great quantities of explosives.

When compared to the extent of the rest of the British chemical industry at the middle of the nineteenth century, or indeed as late as 1875, the explosives industry as a whole was not large. If the existing black gunpowder industry is discounted, it may have been very small indeed. And yet at the same time it must have been one of the biggest, if not the biggest, in the world.

Before 1847 there were of course only gunpowder mills and some small preparation of mercury fulminate at the Royal Laboratory at Woolwich, and perhaps elsewhere to supply the civilian market for percussion caps.

During the year 1847 there was the single small gun-cotton factory of Messrs. Hall and Sons at Faversham. This was as we have seen destroyed in the same year.

Between 1847 and about 1862 there was not, so far as can be shown, any civilian manufacture of explosives in the country at all, other than of black gunpowder.

When nitroglycerine was brought into the country it was imported from Germany and Sweden. Picric acid was a military explosive. It cannot be said whether or not Saxifragine was ever made in the country.

When gun-cotton was at last thought to have been stabilised, it was made at Waltham Abbey for the Government and at the nearby Stowmarket factory of Thomas Prentice and Sons. When at last dynamite was allowed to be made, it was produced only at the Ardeer factory.

One possible cause of these limitations on the scale of production was the provisions of British patent law. The inventor was quite rightly allowed the exclusive enjoyment of the fruits of his ingenuity for a number of years after the granting of his patent. If as a result of the inventor not being able to finance a scale of production which would allow him to supply, say, gun-cotton to anyone who wished to buy it, then that was regrettable. It was not a reason to allow someone else to begin manufacture. Where investment was slow, development was limited. To cite yet again the experiences of both Schönbein and Nobel, they both at some time had to settle for poorer terms for the use of their inventions than they might have done.

The first public step in getting support for a new explosive was to stage a demonstration. This, as has been seen, took what had become a set form. It was required to have some set pieces, usually devised to emphasise the composition's special qualities, fired off in the presence of expert, if not overly critical, and influential witnesses, and hopefully

some potential investors.

When financial support had been found, it was necessary to build a factory. The United Kingdom was at that time probably the easiest country in the world in which to build and equip a factory of any kind, but it was particularly convenient to set up any kind of chemical process. Everything which might be needed was to hand because the country was already the leader in other forms of chemical manufactures. Power plant, and machinery, mill-wrights and fitters, could all be had without having to pay for more than local transport. The greatest advantage was that almost everything could be had 'off-the-shelf'.

Before the legislation of 1875 the setting up of an explosives factory was likely to be little hampered by regulation or legislation. There were laws which controlled the transport and storage of certain explosives and of petrol, and in the special case of nitroglycerine there was an outright prohibition, but there was little control over premises. This is not to say that the owner of an explosives factory was not responsible for what happened as a result of his activities. The nineteenth century was a great time for civil litigation.

Industrial plant used in the manufacture of explosives ranged from the most primitive to the most advanced available. It was possible in most cases to begin production with a minimum of equipment. The cost of setting up any plant other than a gunpowder mill must have been, relatively speaking, low when compared to the cost of setting up, say, a small local gasworks.

Hydraulic machinery was to be important in the making of gunpowder and in the compression of gun-cotton blasting cartridges.

Machinery appears not to have had a long working life in the explosives industry. Several reasons can be suggested to account for this. It may be that there was a need to increase capacity in order to

meet demand more often in an expanding business. It may be that continuous working was the custom. This was the practice in some gunpowder mills. It may be that ever increasing mechanisation was an absolute necessity in order to maintain competitiveness: not so much, in those days, to dispense with labour as to have a capacity to fill a large order very quickly. Or, conversely, and in the case of gunpowder making, an efficient well capitalised mill would be able to drive less efficient mills out of the trade under conditions of slowly falling demand.

Workpeople are accorded very little notice or mention in the literature. The work was labour intensive throughout all stages of manufacture in the early days but later, after about 1865, more machinery came into use. The making and packing phases of the processes remained labour intensive. No element of danger money or hard-laying allowances appears to have been paid. Compensation after explosions is sometimes mentioned, but it was always on a voluntary basis. In general, explosives workers were not well paid. Most explosives factories were located where there was little in the way of alternative employment except farming, which was also ill-paid and also arduous. It is hard to say how much specialisation there was throughout the process. Work regimes having regard to sobriety and safety were only officially enforced after 1875.

The list of names in the history of British explosives technology is very short. And those names which do appear also occur and recur elsewhere in connection with all manner of enterprises and researches. The reasons for this phenomenon are simple enough. The years between 1847 and 1875 were easily encompassed by the careers of a few men who had so much to do with progress in explosives. These men knew one another through their often multiple membership of institutes and societies. It was still a time when it was possible for a man to keep

himself abreast of all that was happening in several branches of science or technology. Often a scientific interest was combined with actual ownership. The death of two of Thomas Prentice's sons in the Stowmarket explosion showed that in that case at least two of the family were working in the technical management of the business. There was also an element of status-marking in the right to utter papers. Only principals could communicate. This is not unknown even today. An employee, even though he might be a 'gentleman' and a well-educated professional in his own right, would not be encouraged to communicate - without leave - the secrets of what would have been generally held to be his employer's business. It simply was not his place to do so. The owner of a patent for a doubtful chlorate composition, mixed in his own back kitchen, could write and publish what he pleased.

In this matter the position of A.F. Abel is remarkable. As chief chemist to the War Office he was clearly a public servant. He was also connected with the civilian manufacture of gun-cotton in that it was his patent which was used for the Stowmarket process. Abel appears to have been able to have supported a constructive conflict of interest in at least this sphere of his work for many years.

The greatest single respect in which progress in explosives differed from advances in other and closely related branches of applied chemistry during the middle part of the nineteenth century was in the pace of development. Development from invention to safe application was notably irregular. This in its turn may have influenced the amount of research which was attracted to explosives generally.

A mistake in the mixing of a vat of dyestuff is at worst a local tragedy. A minute but uncontrolled chemical reaction in a batch of explosives can, and did, lead to enormous effects upon public confidence,

investment, and legislation. The long pauses in the development of both gun-cotton and nitroglycerine came about because of such minute errors.

It was not that theoretical knowledge of chemistry was deficient. There was not always agreement about the actual causes of accidents, but the true causes, as they were later confirmed to be, were among those strongly suspected.

The overall reason for the accidental explosions was, it is proposed, the contemporary attitude to and perception of chemical purity. A similar gap was experienced in the attitude which was at the same period displayed towards asepsis in medicine. How clean is clean? Was appearing to be spotless the same thing as being sterile? Was a neutral reaction from a sample of gun-cotton an indication that a hundredweight batch was free of acid? Experience suggests that a man might know intellectually that certain dangers are inherent in an action, but this does not always prevent that action. In mid-Victorian times, in England, and under the economic system prevailing then, it was very much the case that a man had a living to make.

But in the special case of explosives there can be no acceptable failure rate in the quality control; though in practice there has to be a failure rate which is accepted. There cannot be many instances in the history of technology where the want of what was after all a mechanical change in processing had such long lasting effects.

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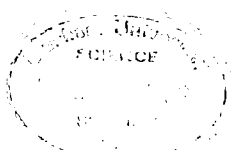
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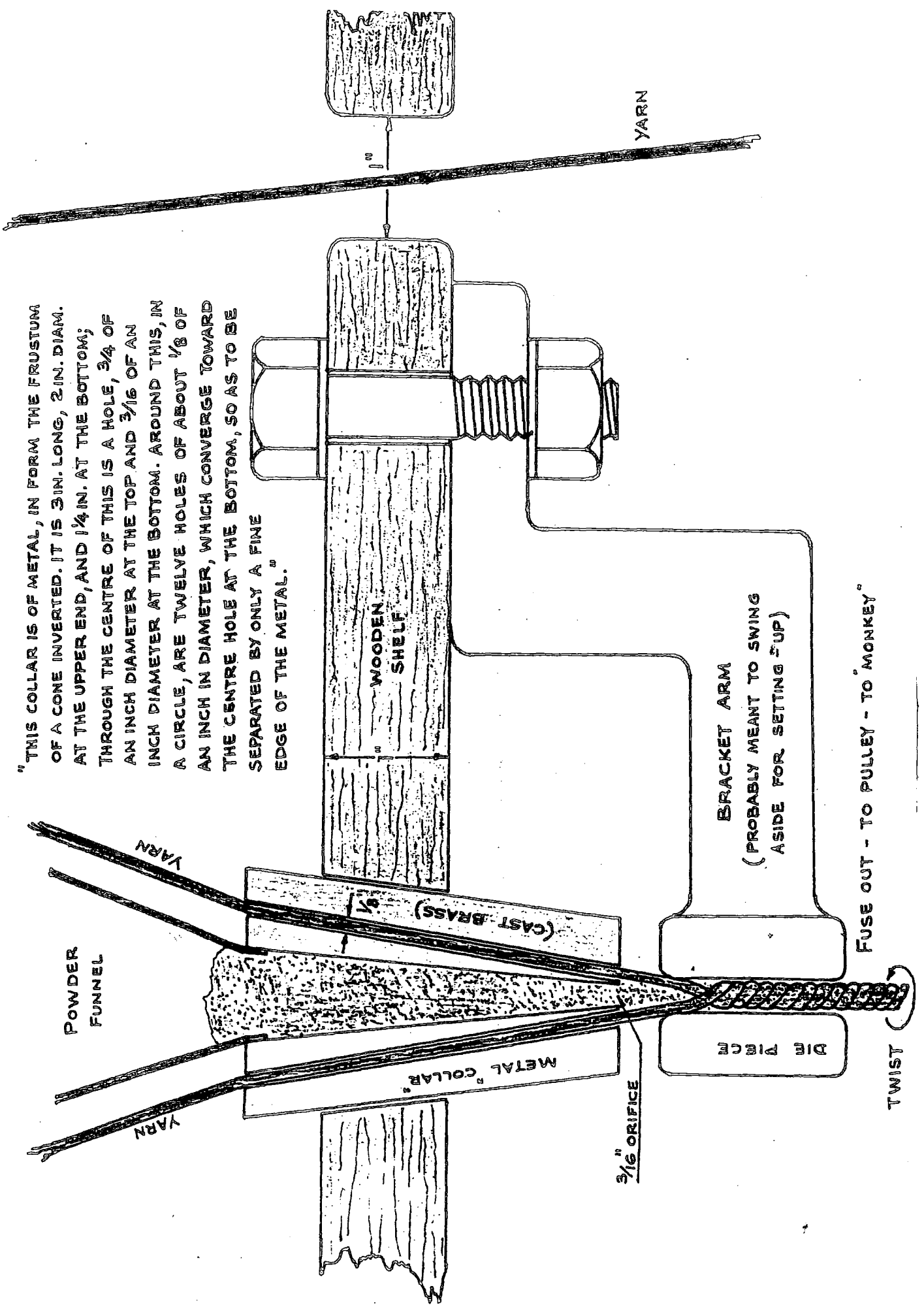
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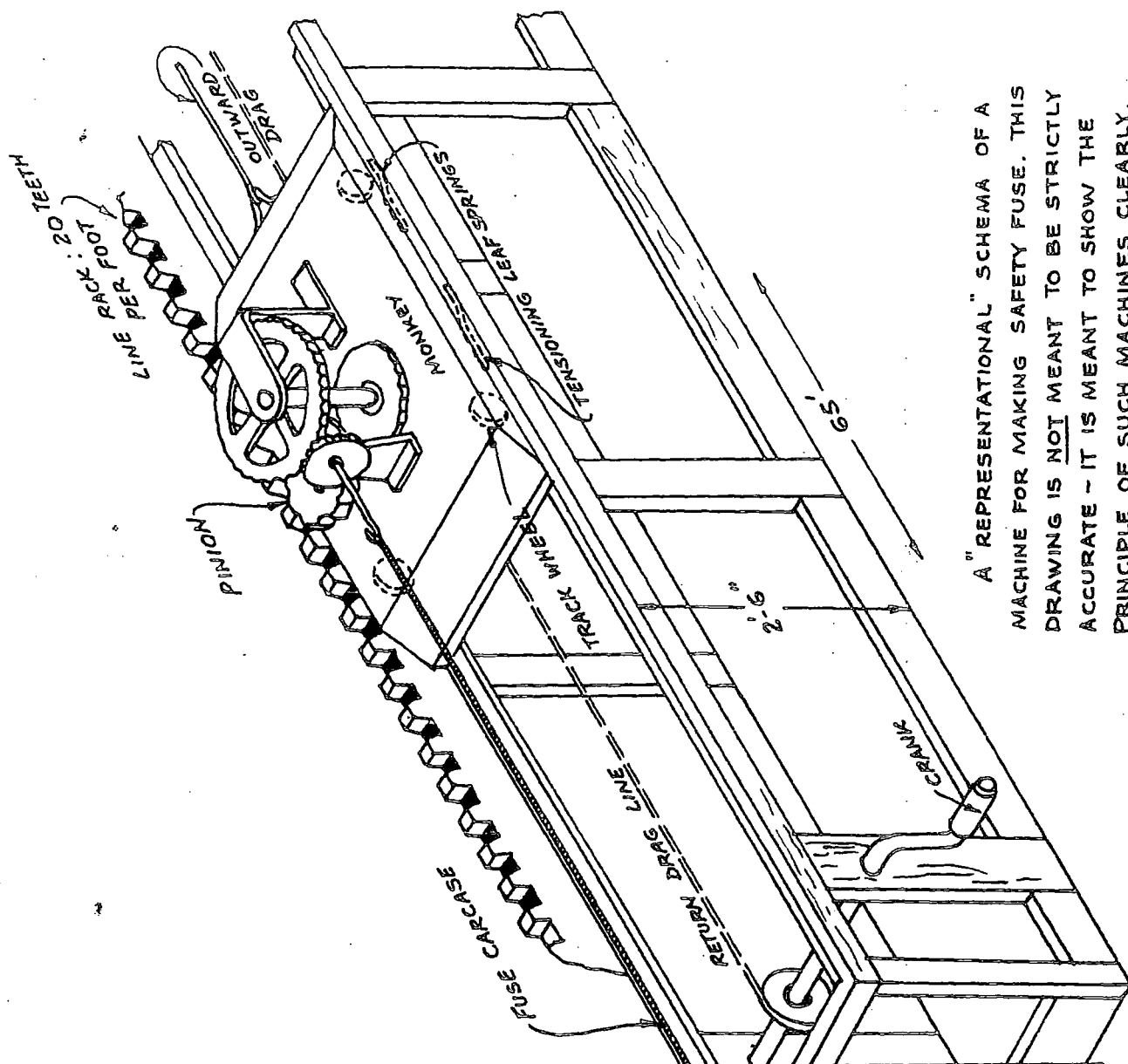
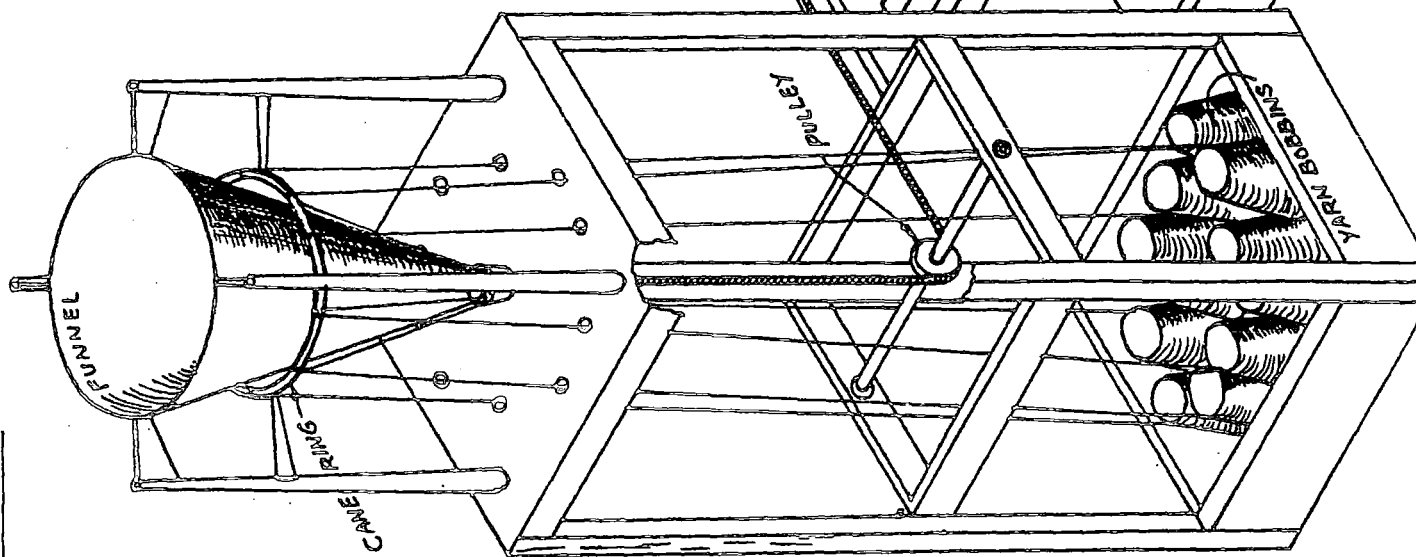
APPENDIX II

DRAWING ONE

SCALE : FULL SIZE - AS PATENT SPECIFICATION



DRAWING TWO



A "REPRESENTATIONAL" SCHEMA OF A MACHINE FOR MAKING SAFETY FUSE. THIS DRAWING IS NOT MEANT TO BE STRICTLY ACCURATE - IT IS MEANT TO SHOW THE PRINCIPLE OF SUCH MACHINES CLEARLY.